

EXPLORING THE CHEMICAL REACH OF THE MJO USING THE A-TRAIN DATA

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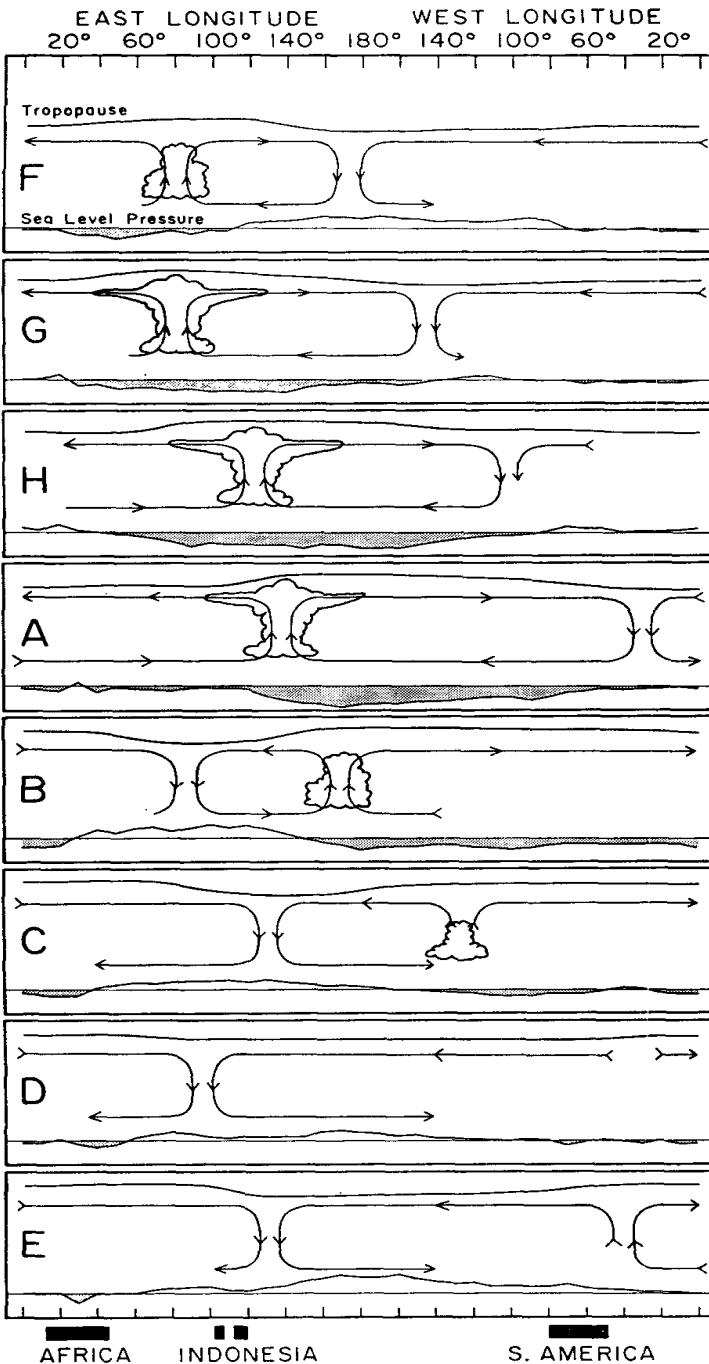
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OUTLINE

- ☒ Introduction to the MJO
- ☒ Motivation
- ☒ A-Train Atmospheric Composition Data
 - AIRS, CALIOP, MODIS, MLS, OMI, TES
- ☒ Result Highlights
 - H₂O, aerosols, O₃, CO₂
- ☒ Summary

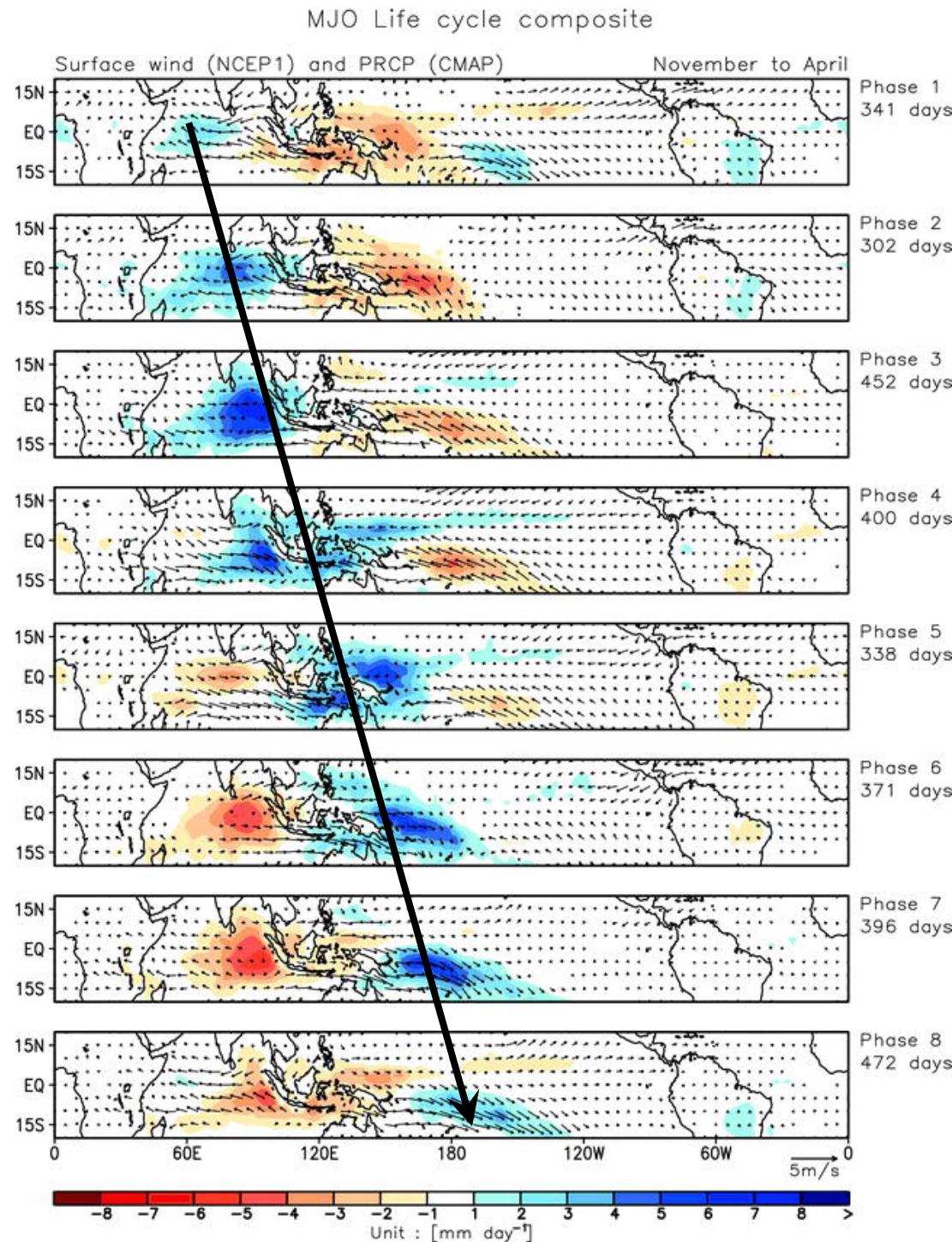


MADDEN-JULIAN OSCILLATION (MJO) (A.K.A. INTRASEASONAL OSCILLATION)

- ❖ The MJO is characterized by slow eastward-propagating oscillations in tropical deep convection and large-scale circulation.
- ❖ It is the dominant form of intra-seasonal variability in the Tropics.
- ❖ It impacts a wide range of phenomena.
- ❖ It is predictable within 2-4 weeks.
- ❖ Our weather & climate models have a relatively poor representation.
- ❖ A comprehensive theory for the MJO is still lacking.

*Madden & Julian [1971; 1972],
Lau and Waliser [2005], Zhang [2005]*

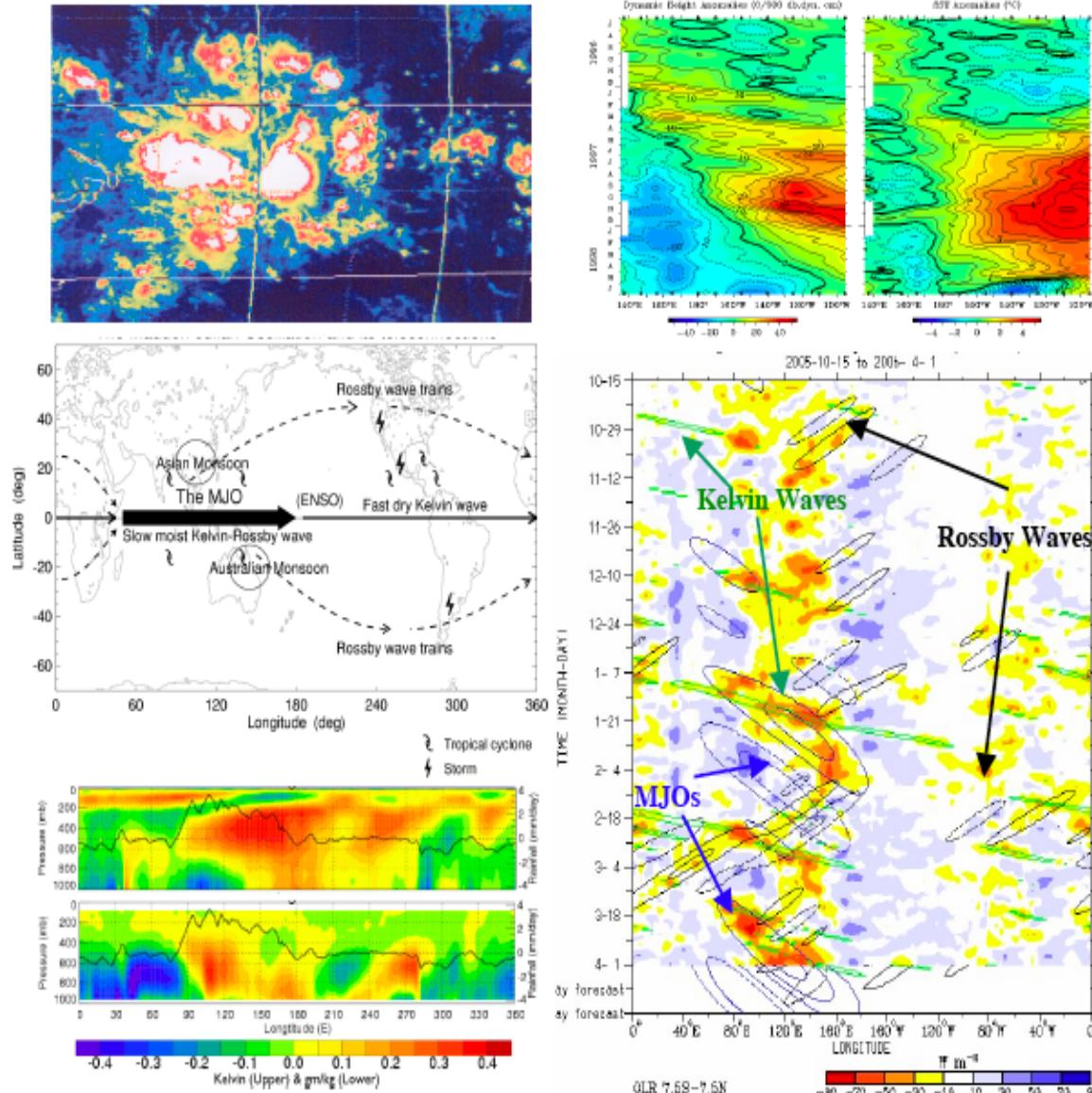
A COMPOSITE MJO CYCLE IN N.H. WINTER (Nov-APR)



- Rainfall (convection) anomalies propagate eastward and mainly affect the tropical eastern hemisphere.
- Surface wind anomalies also propagate eastward and can affect the global tropics.

Fig. 12 of Waliser et al. [2009]

MJO IMPACTS

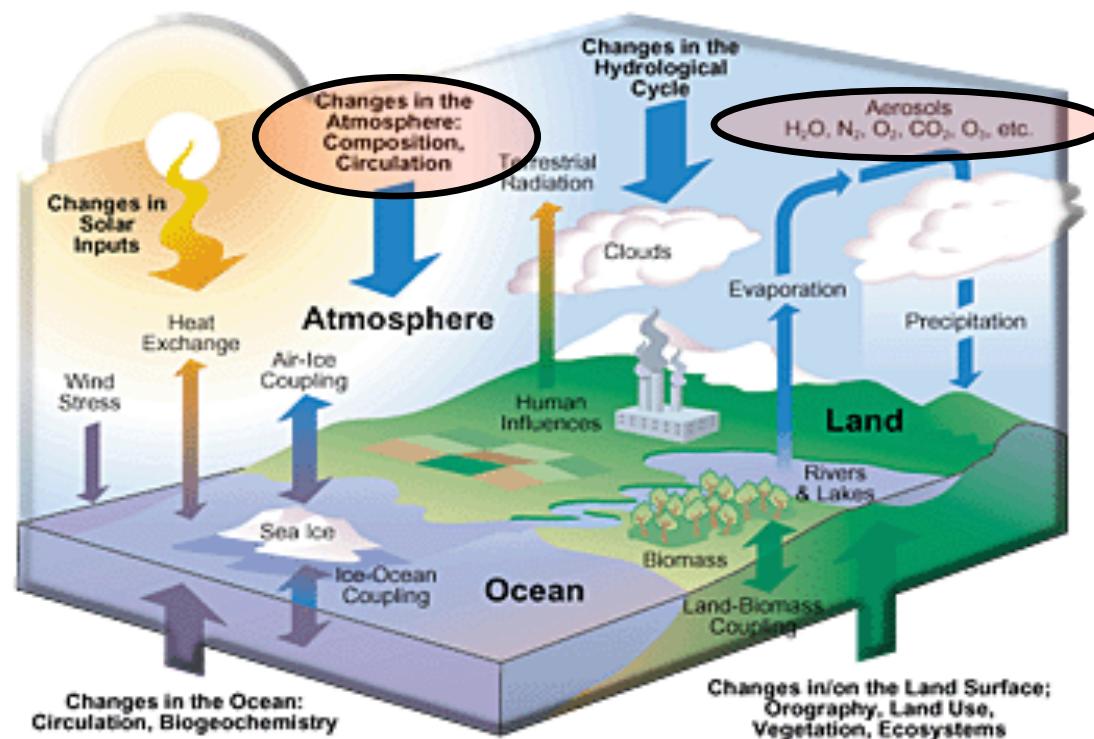


To date, influences of the MJO on the physical components of global climate system have been well recognized, documented, and in some cases, also well understood (e.g., monsoon, ENSO, hurricane, and extratropical weather)

MOTIVATION

However, the impacts of the MJO on the chemical component of the climate system have been realized only recently and have not been well documented and understood (e.g., *Li et al.* [2010]; *Tian et al.* [2007, 2008, 2010]; *Weare* [2010]; *Wong and Dessler* [2007]; *Ziemke and Chandra* [2003]; *Ziemke et al.* [2007]).

Global Climate System Components



A-TRAIN CONTRIBUTION

The currently available high spatial and temporal resolution A-Train atmospheric composition data provide us an unprecedented opportunity to study the MJO's impacts on atmospheric composition.

A-TRAIN ATMOS COMPOSITION DATA

Sensors	Products	Resolution (H, V)	Height Range	Record Length
AIRS/Aqua	H ₂ O profile	45 km, 2 km	>=300hPa	09/2002-pres
	Temp profile	45 km, 2 km	>=10hPa	
	O ₃	45 km	Total Col	
	CO	45 km	Mid-Trop	
	CO ₂	90 km	Mid-Trop	
	Dust	45 km	Total Col	
CALIOP/CALIPSO	Aerosol profile	40km, 120m/360m	<20 km/20-30km	06/2006-pres
MODIS/Aqua	AOT	10km	Total Col	07/2002-pres
MLS/Aura	H ₂ O profile	160 km, 3 km	<=316hPa	08/2004-pres
	O ₃ profile	160 km, 3 km	<=215hPa	
	CO profile	300 km, 4.5 km	<=316hPa	
OMI/Aura	Total O ₃	13 x 24 km	Total Col	08/2004-pres
	O ₃ profile	13 x 48 km, 10 km	<60km	
	AI/AOT	13 x 24 km	Total Col	
TES/Aura	O ₃ profile	175 km, 8 km	700-10hPa	08/2004-pres
	HDO		>550hPa	

VERTICAL MOIST STRUCTURE OF THE MJO

❖ Science question:

What is the large-scale vertical moist structure of the MJO?

❖ A-Train contribution: AIRS/Aqua

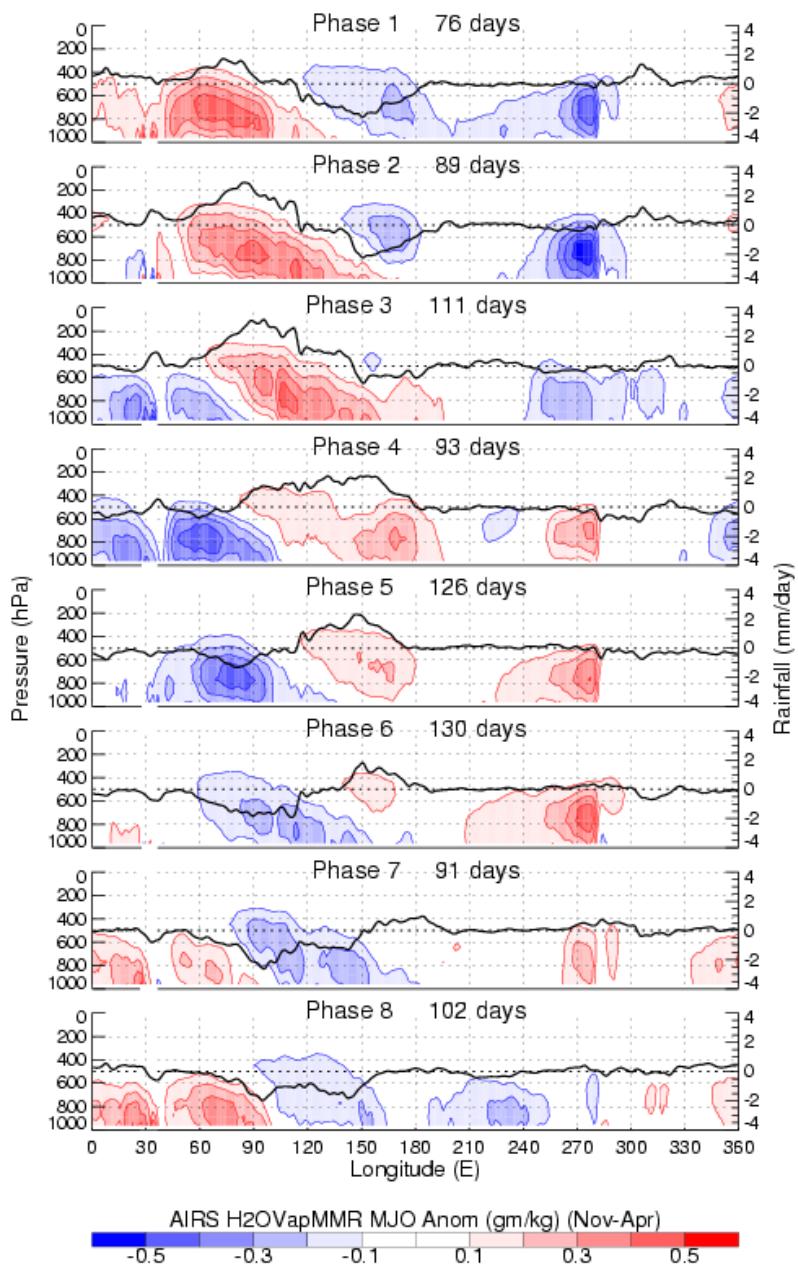
AIRS provides 2X daily global H₂O profiles with vertical resolution of 1–2 km, horizontal resolution of 45 km, and radiosonde accuracy for cloud cover up to about 70%.

❖ Results:

AIRS data provide a well-sampled global vertical moist structure of the MJO.

❖ Implications: This result helps to better understand the MJO dynamics and also offers a useful observation-based metric for climate models.

Tian et al. [2006; 2010]



MJO-RELATED AEROSOL VARIATION

❖ Science question:

Does the MJO influence the aerosol variability? [Tian et al. 2008]

❖ A-Train contribution: MODIS/Aqua

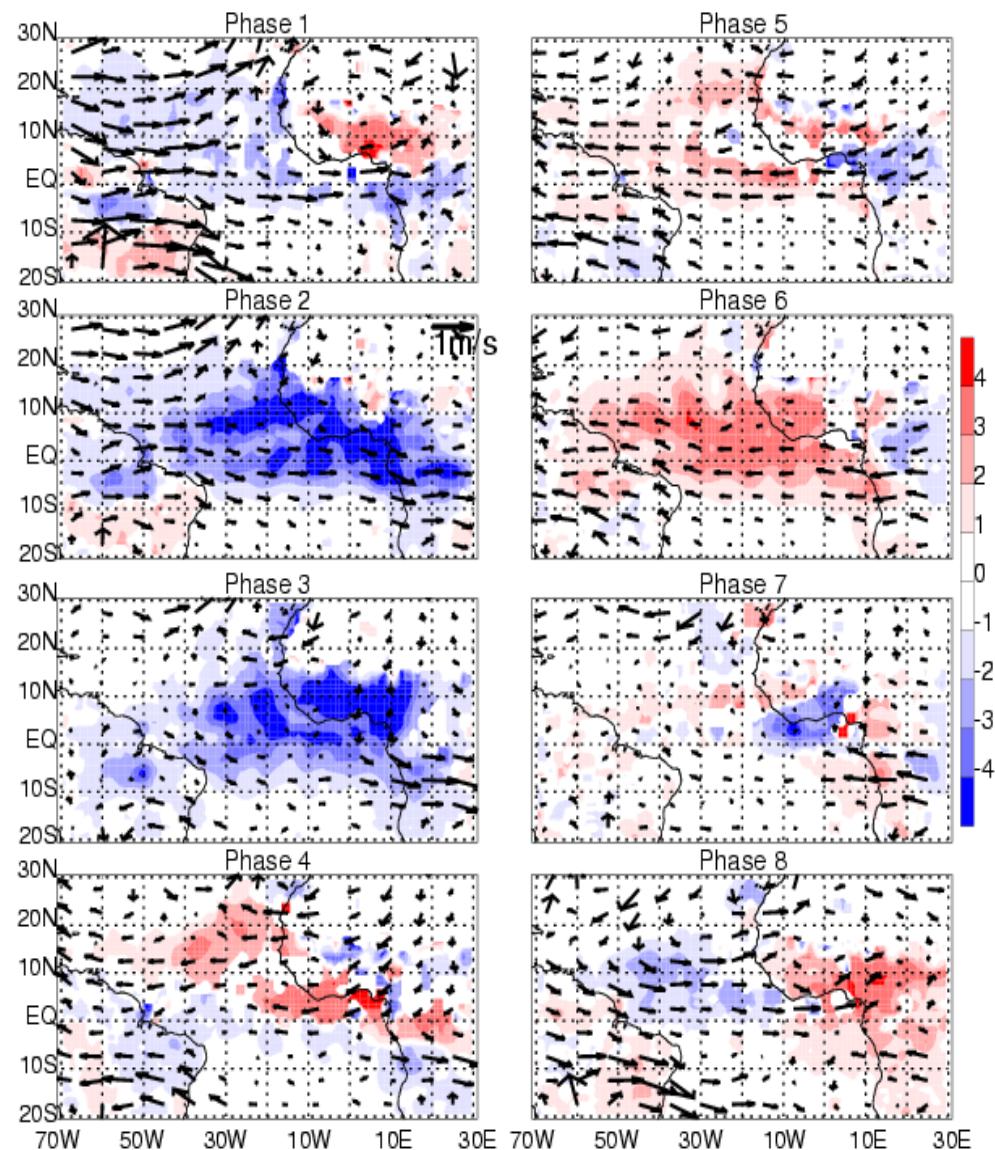
MODIS/Aqua provides high-quality daily aerosol optical thickness (AOT) over oceans for clear-sky conditions.

❖ Results:

The MJO does influence the aerosol variability over the tropical Atlantic.

❖ Implications:

Atlantic aerosol concentration might have predictable components with lead times of 2-4 weeks.



Tian et al. [2010]

MJO-RELATED TOTAL O₃ VARIATION

❖ Science question:

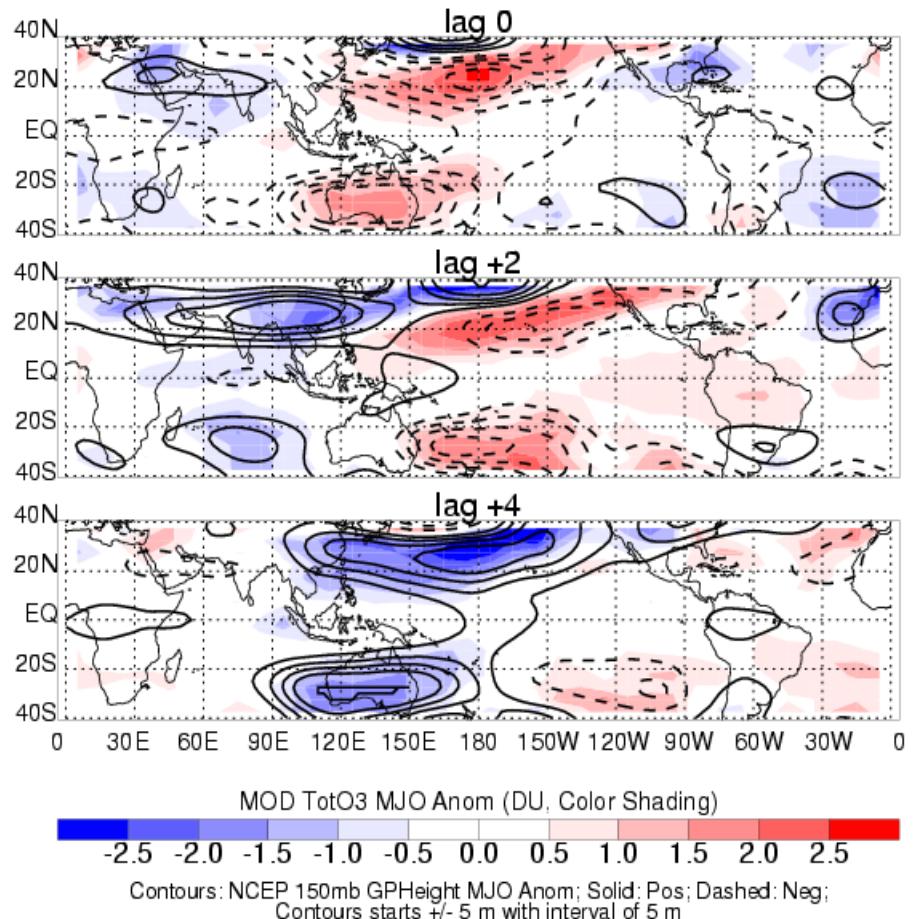
Does the MJO influence the tropical total column O₃?

❖ A-Train contribution: AIRS/Aqua

AIRS/Aqua and TOMS/Nimbus-7 provide total O₃.

❖ Results:

The MJO does influence the tropical total column O₃. Based on AIRS and TOMS total O₃ data, it is found that the MJO-driven total O₃ variations are mainly evident in the subtropics and related to the vertical movement of subtropical tropopause, while they are very small over the equatorial regions.



Tian et al. [2007]

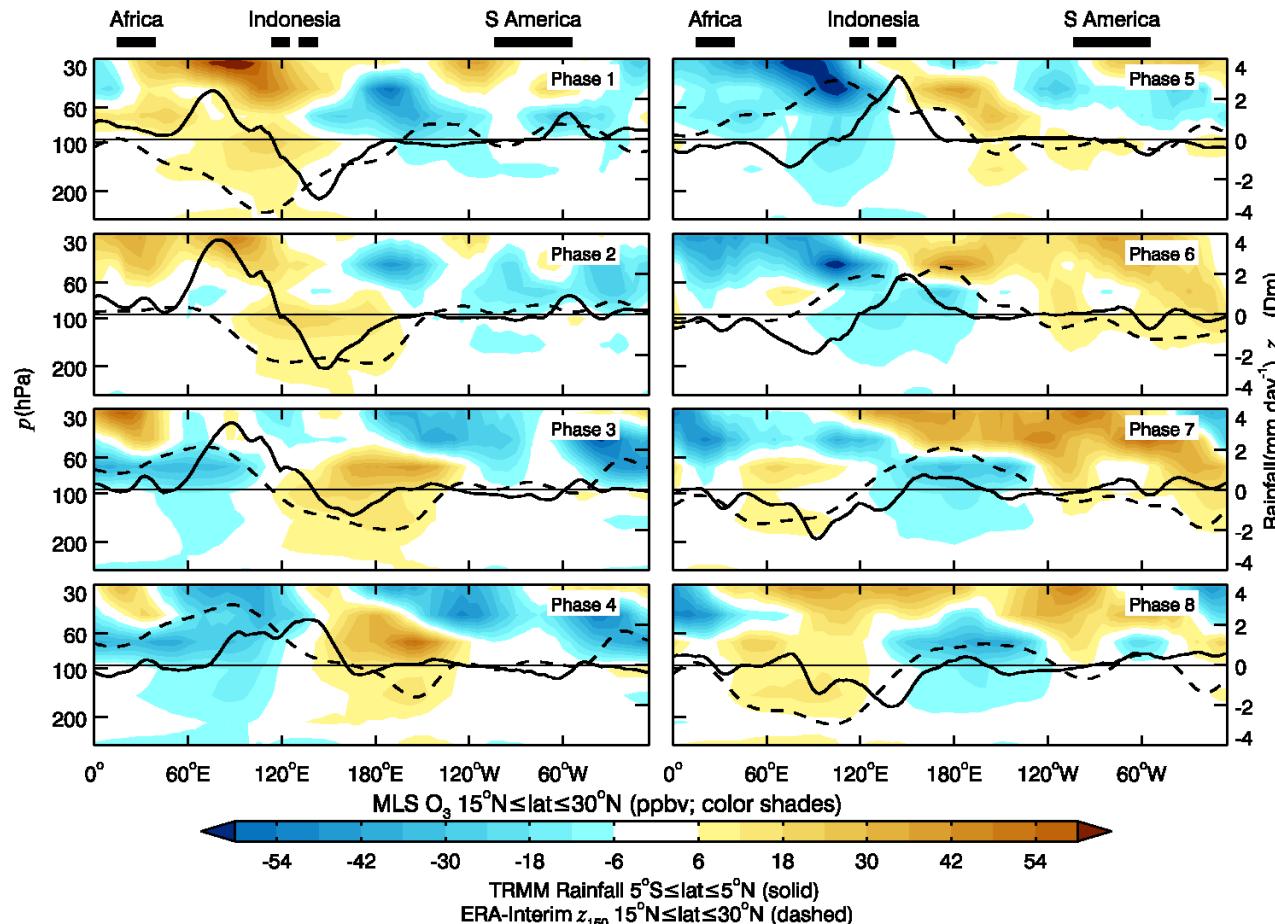
MJO-RELATED O₃ VARIATION

❖ Science question:

Do the O₃ profiles from satellites support the notion of Tian et al. [2007]?

❖ A-Train contribution: MLS/Aura and TES/Aura

MLS/Aura and TES/Aura both provide O₃ profiles.



Li et al. [2010]

MJO-RELATED MID-TROP CO₂ VARIATION

☒ Science question:

Does the MJO influence the CO₂ variations?

☒ A-Train contribution: AIRS/Aqua

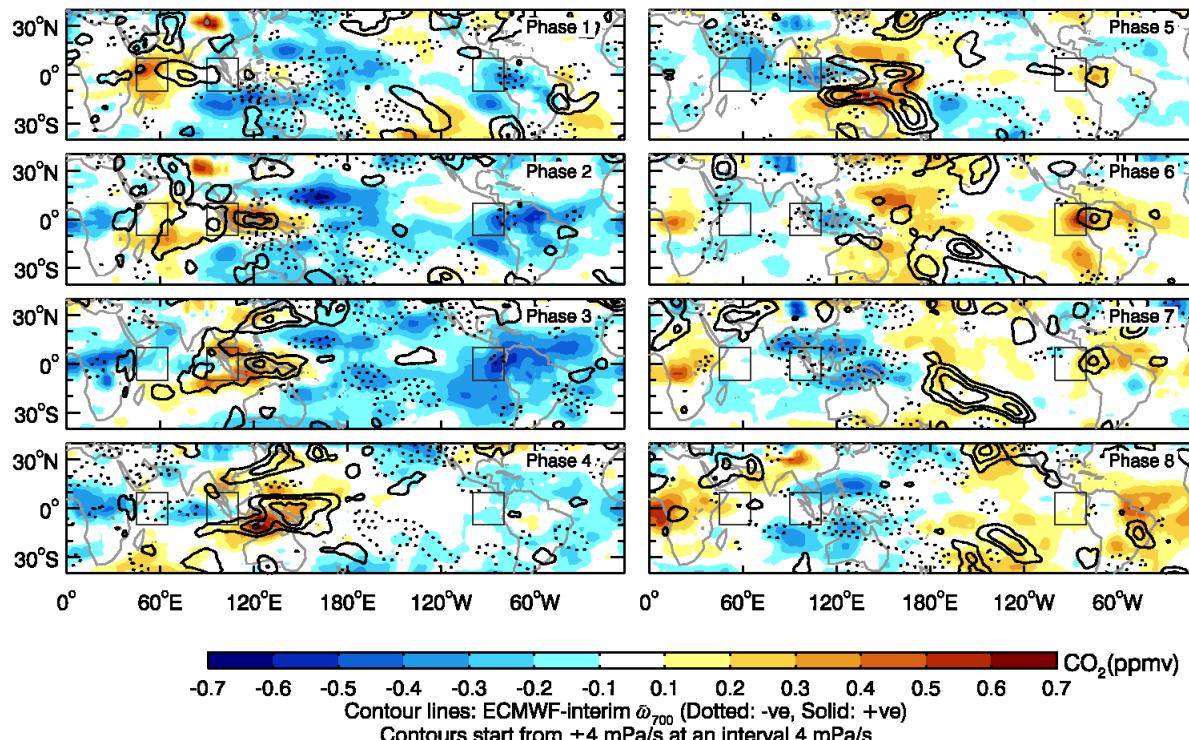
AIRS provides a first global daily mid-tropospheric (~400 hPa) CO₂.

☒ Results:

There is a MJO signal in the AIRS mid-tropospheric CO₂ data that appears to be driven by the lower-tropospheric large-scale vertical motions associated with the MJO.

☒ Implications:

These findings will provide a robustness test for coupled carbon–climate models. They also imply that surface CO₂ values are higher than those in the upper-troposphere.



Li et al. [2010]

SUMMARY

- ❖ The MJO is the dominant component of the intraseasonal (30–90 day) variability in the tropical atmosphere.
- ❖ The currently available A-Train atmospheric composition data provide us an unprecedented opportunity to study the MJO's impacts on atmospheric composition.
- ❖ Our results indicate that the MJO can impact a number of important atmospheric constituents, such as H₂O, aerosols, O₃, and CO₂.
- ❖ Our results provide a better understanding of the intraseasonal variability of atmospheric composition and an important test for chemical transport models.
- ❖ Our results imply that some atmospheric constituents may be predictable with lead times of 2-4 weeks.

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- 4) Schwartz, M. J. D. E. Waliser, B. Tian, D. L. Wu, J. H. Jiang, and W. G. Read, 2008: Characterization of MJO-related upper-tropospheric hydrological processes using MLS. *Geophys. Res. Lett.*, **35**, L08812, doi:10.1029/2008GL033675.
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- 6) Li, K.-F., B. Tian, D. E. Waliser, and Y. L. Yung, 2010: Tropical mid-tropospheric CO₂ variability driven by the Madden-Julian Oscillation. *Proc. Nat. Acad. Sci.*, doi:10.1073/pnas.1008222107, in press.
- 7) Tian, B., D. E. Waliser, R. A. Kahn, and S. Wong (2010), Modulation of Atlantic aerosols by the Madden-Julian Oscillation, *J. Geophys. Res.*, submitted.
- 8) Tian, B., and D. E. Waliser, 2010: Chemical and biological impacts. Chapter 13.4 of *Intraseasonal Variability of the Atmosphere-Ocean System (2nd Edition)*, Edited by K.-M. Lau and D. E. Waliser, submitted.
- 9) Li, K.-F., B. Tian, D. E. Waliser, Y. L. Yung, M. J. Schwartz, J. L. Neu, and J. R. Worden (2010), Vertical structure of MJO-related subtropical ozone variations from MLS, TES and SHADOZ data, *J. Geophys. Res.*, in prep.
- 10) Tian, B., D. E. Waliser, Y. L. Yung, and J. R. Worden (2010), MJO-related HDO variations from TES data, *J. Geophys. Res.*, in prep.

BACKUP SLIDES

GENERAL ANALYSIS METHODOLOGY

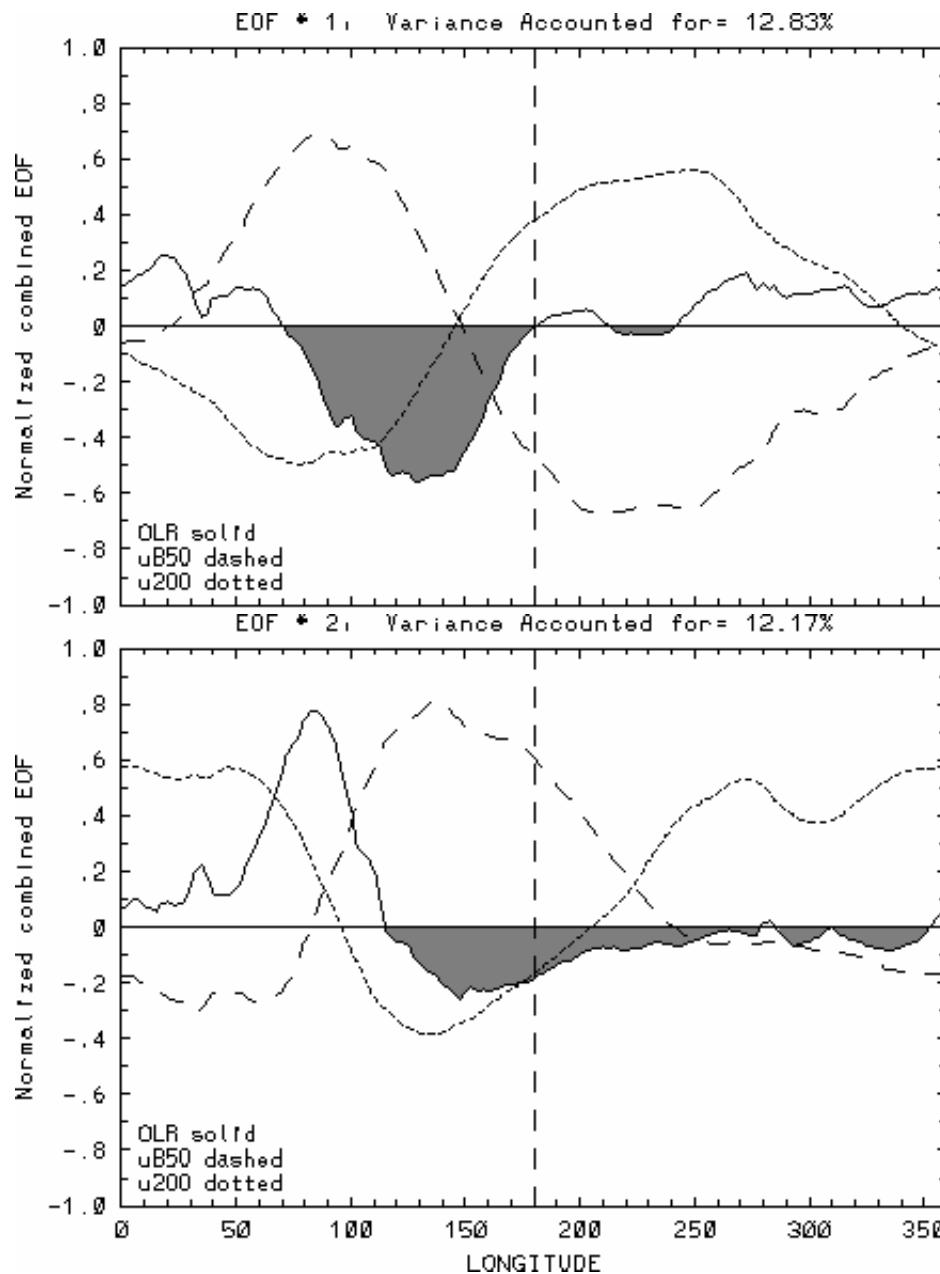
- (1) Intraseasonal anomalies of daily data were obtained by removing the climatological seasonal cycle and data filtering through a 30–90-day band pass filter.
- (2) The MJO phase for each day is determined by the Real-time Multivariate MJO (RMM) index (a pair of PC time series called RMM1 and RMM2) available from 1974 to present at <http://www.cawcr.gov.au/bmrc/clfor/cfstaff/matw/maproom/RMM/>.
- (3) A composite MJO cycle (8 phases) was calculated by averaging band-passed daily anomalies of target quantity for each phase of the MJO cycle.

Wheeler and Hendon (2004)

THE RMM INDEX

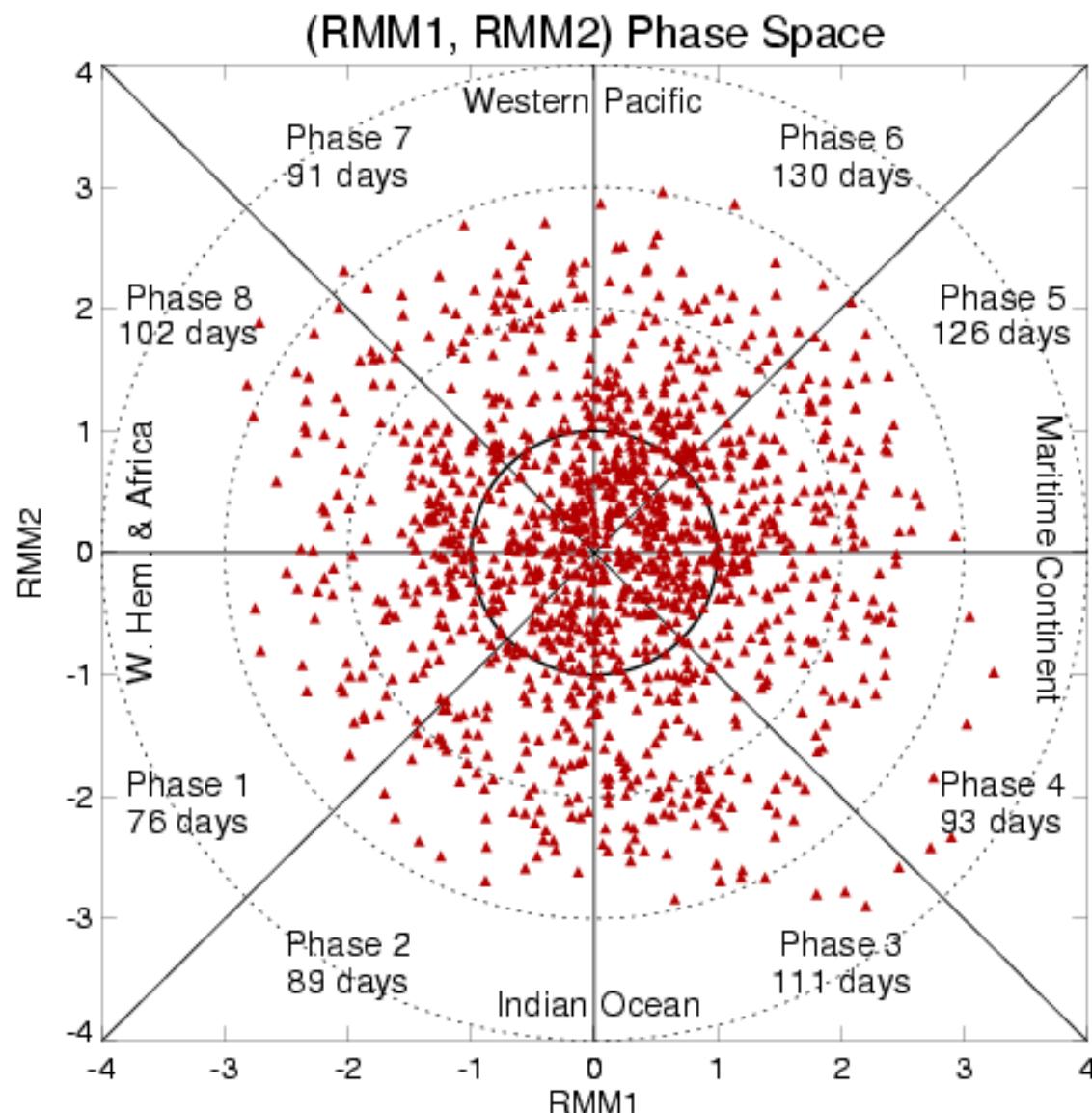
The Real-time Multivariate MJO (RMM) index is the projection of the daily observed NOAA outgoing longwave radiation (OLR) and NCEP/NCAR reanalysis and/or Australian Bureau of Meteorology Research Center Global Analysis and Prediction (GASP) analysis 850- and 200-hPa zonal winds, with the annual cycle and components of interannual variability removed, on a pair of multiple-variable empirical orthogonal functions (EOFs). Two such EOFs are the leading pair of EOFs of the combined daily intraseasonal filtered fields of near-equatorially averaged (15°S - 15°N) NOAA OLR and NCEP/NCAR 850- and 200-hPa zonal winds for all seasons from 1979 to 2001 (23 years).

SPATIAL STRUCTURES OF EOF 1 & 2

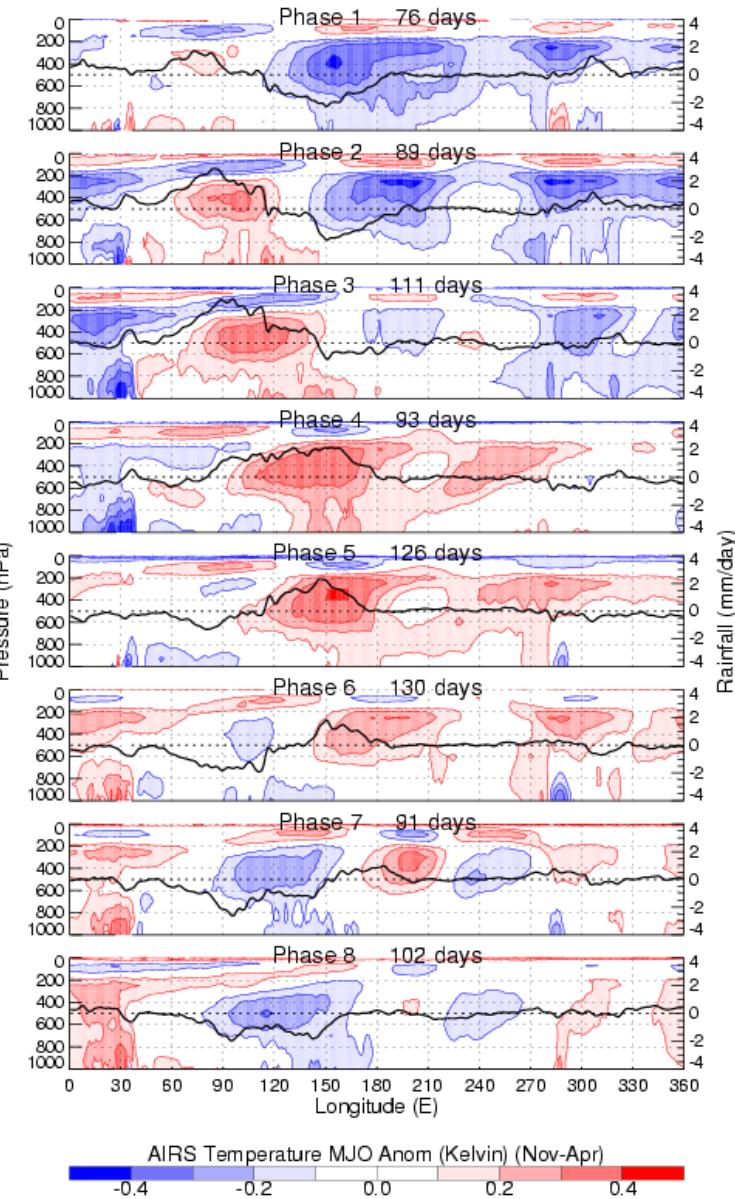
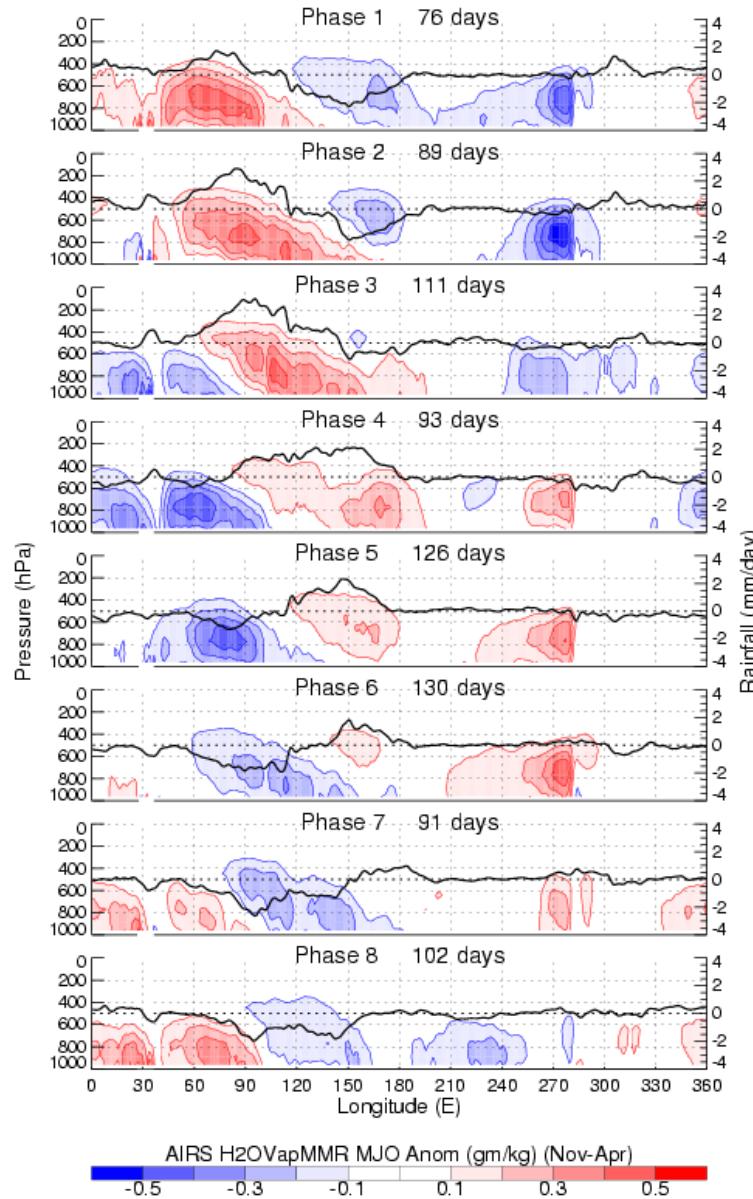


EOF1 describes the situation when the MJO produces enhanced convection (negative OLR anomalies) at the Maritime Continent (MC): low-level westerly wind anomalies extend throughout the Indian Ocean (IO) and MC, and low-level easterlies exist across the Pacific, while upper-level wind anomalies are in the opposite direction to those below. EOF2 has enhanced convection over the Pacific Ocean and wind patterns that are in close quadrature to those of EOF1. Together, they describe the key features of the MJO, such as eastward propagation of convection anomalies in the Eastern Hemisphere; out-of-phase relationship between lower and upper-tropospheric wind anomalies; the predominance of lower-tropospheric westerly anomalies near and to the west of enhanced convection.

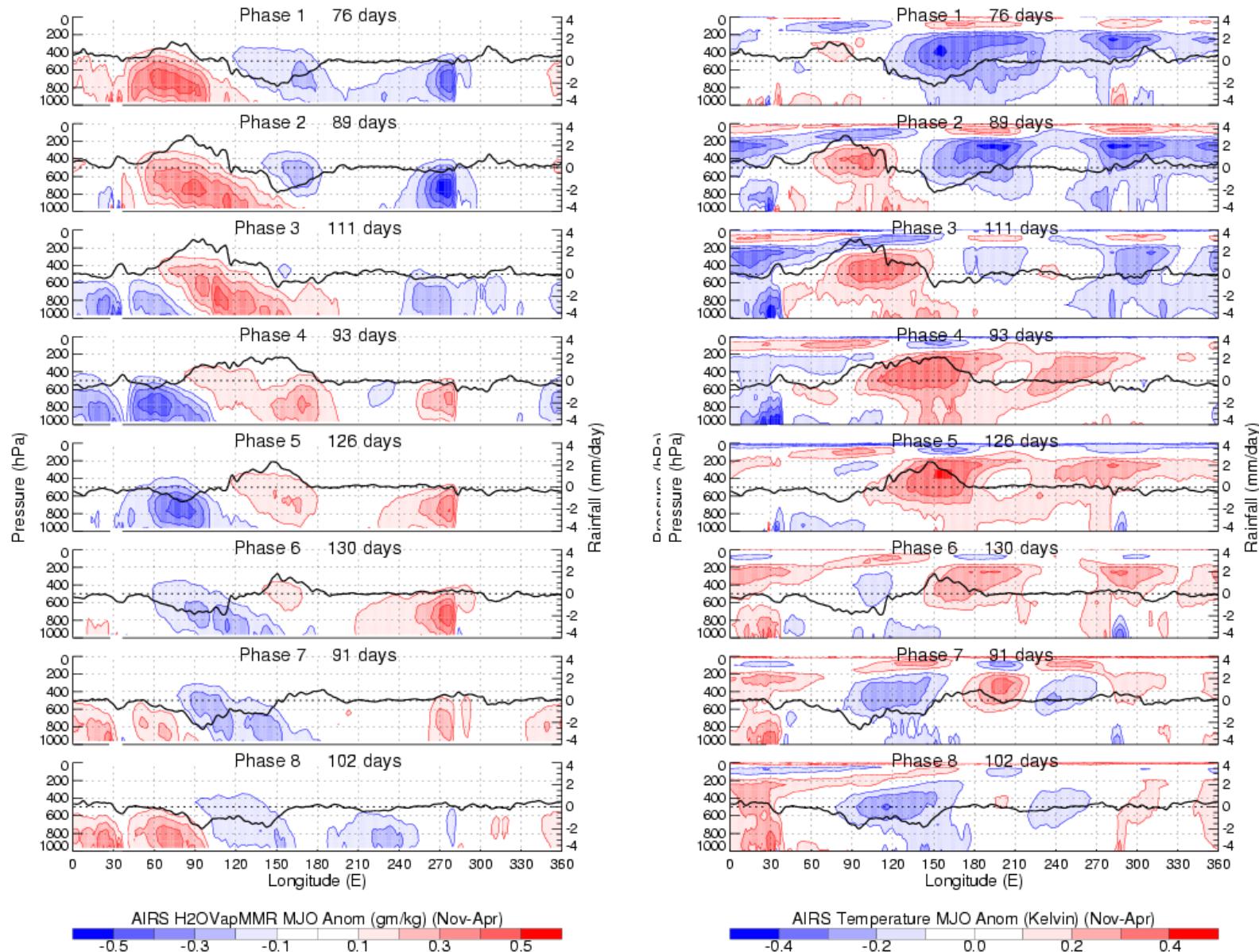
RMM PHASE SPACE FOR AIRS PERIOD



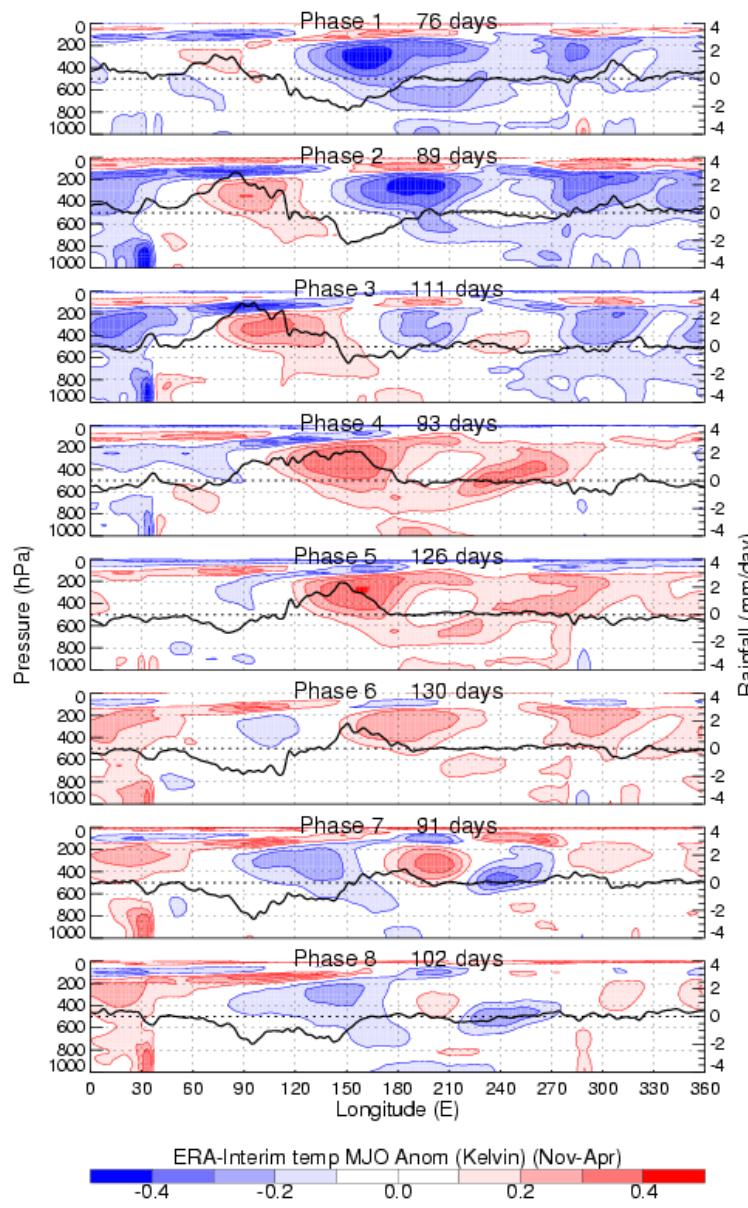
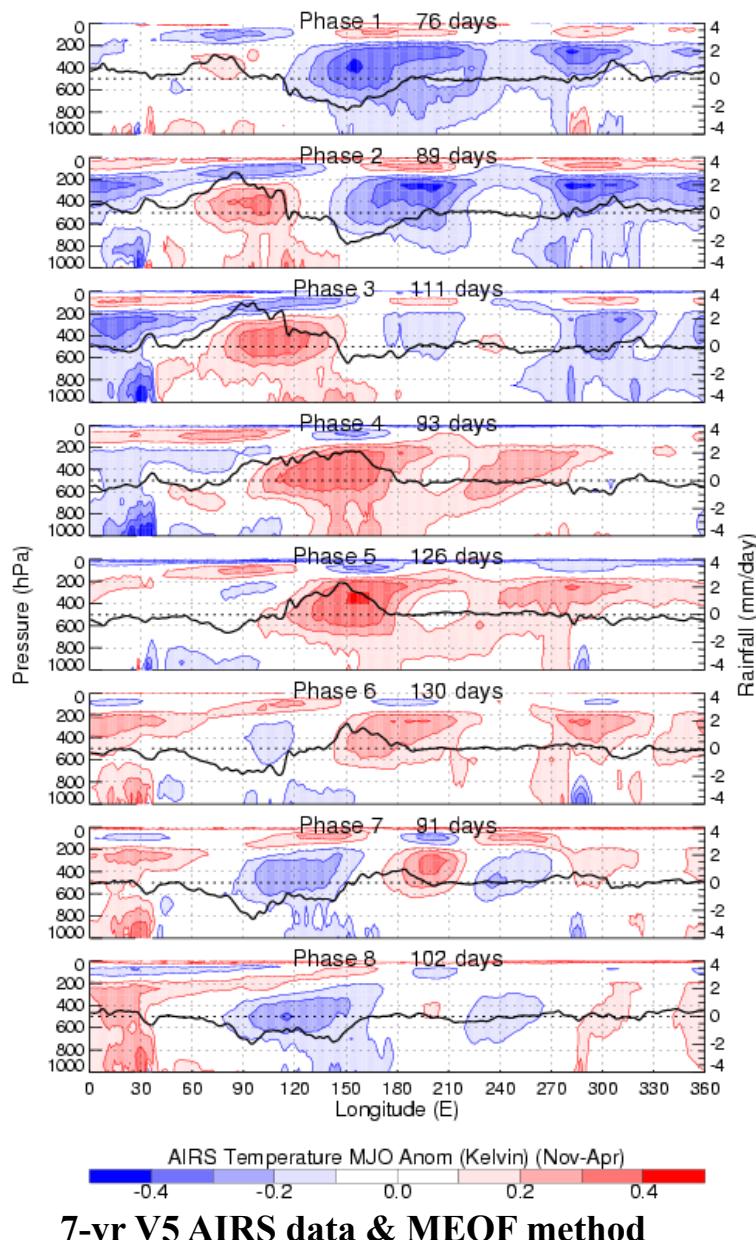
VERTICAL STRUCTURE OF THE MJO FROM AIRS



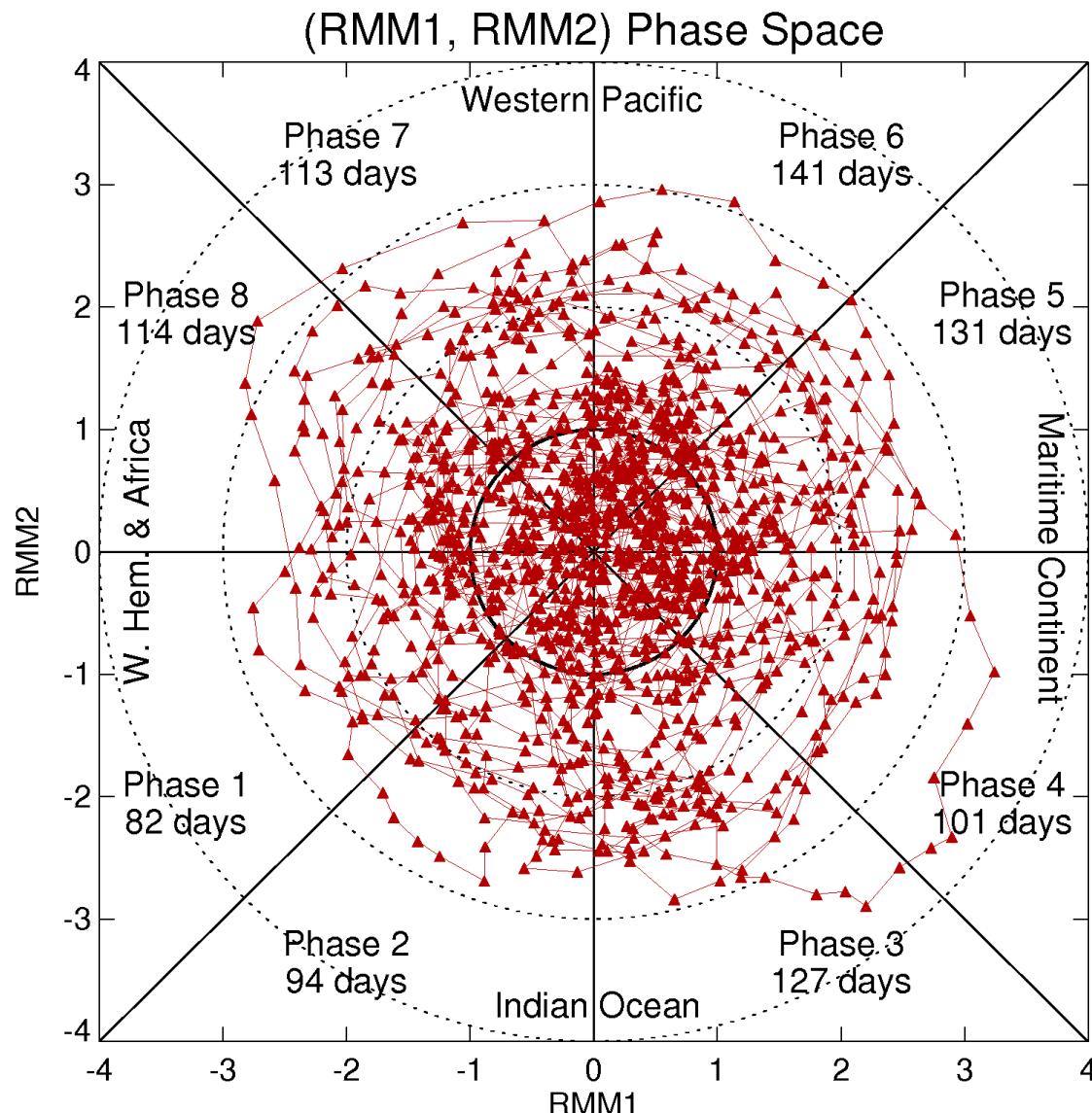
VERTICAL MOIST STRUCTURE OF THE MJO FROM AIRS AND ECMWF



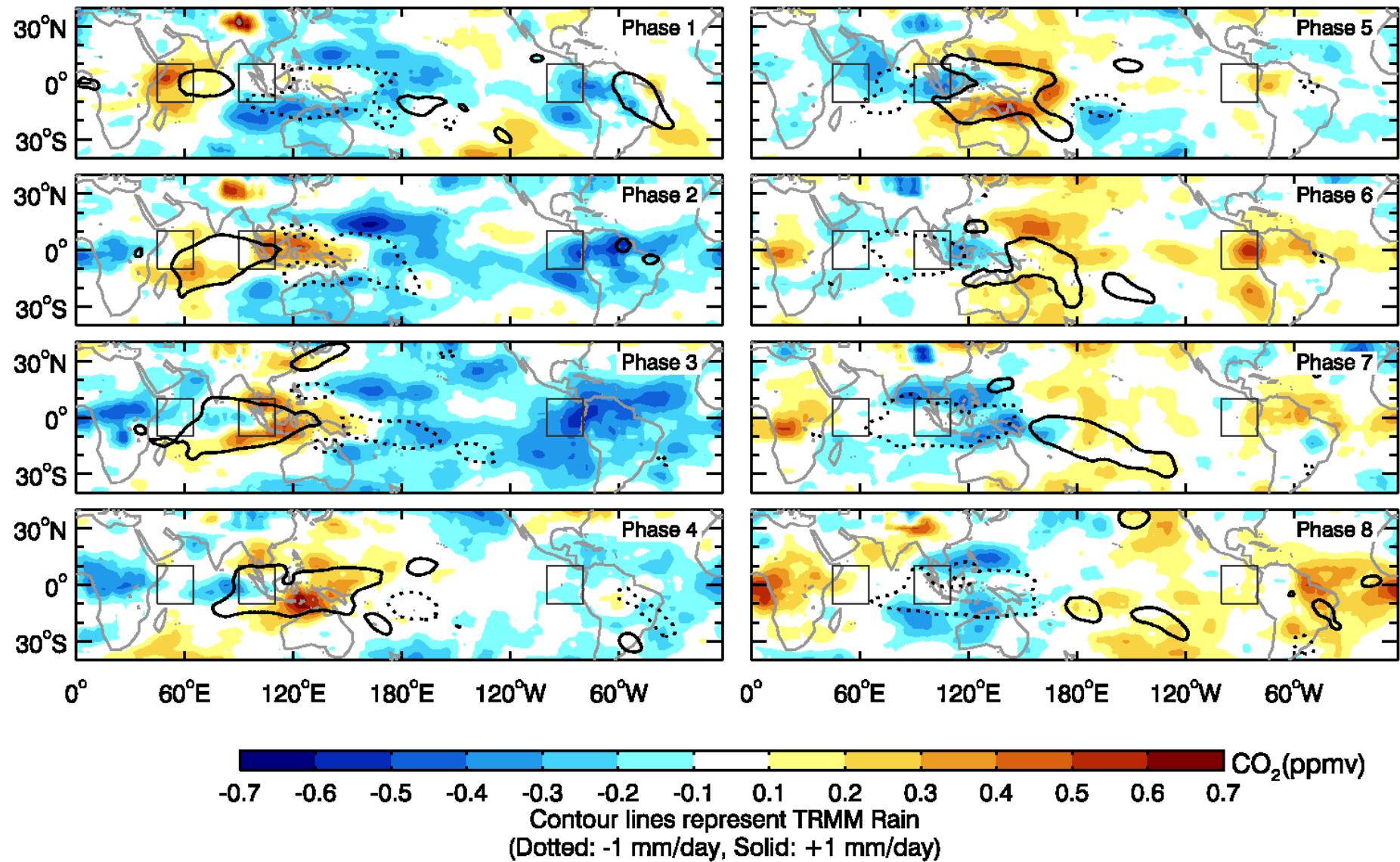
COMPARISON OF AIRS AND ECMWF



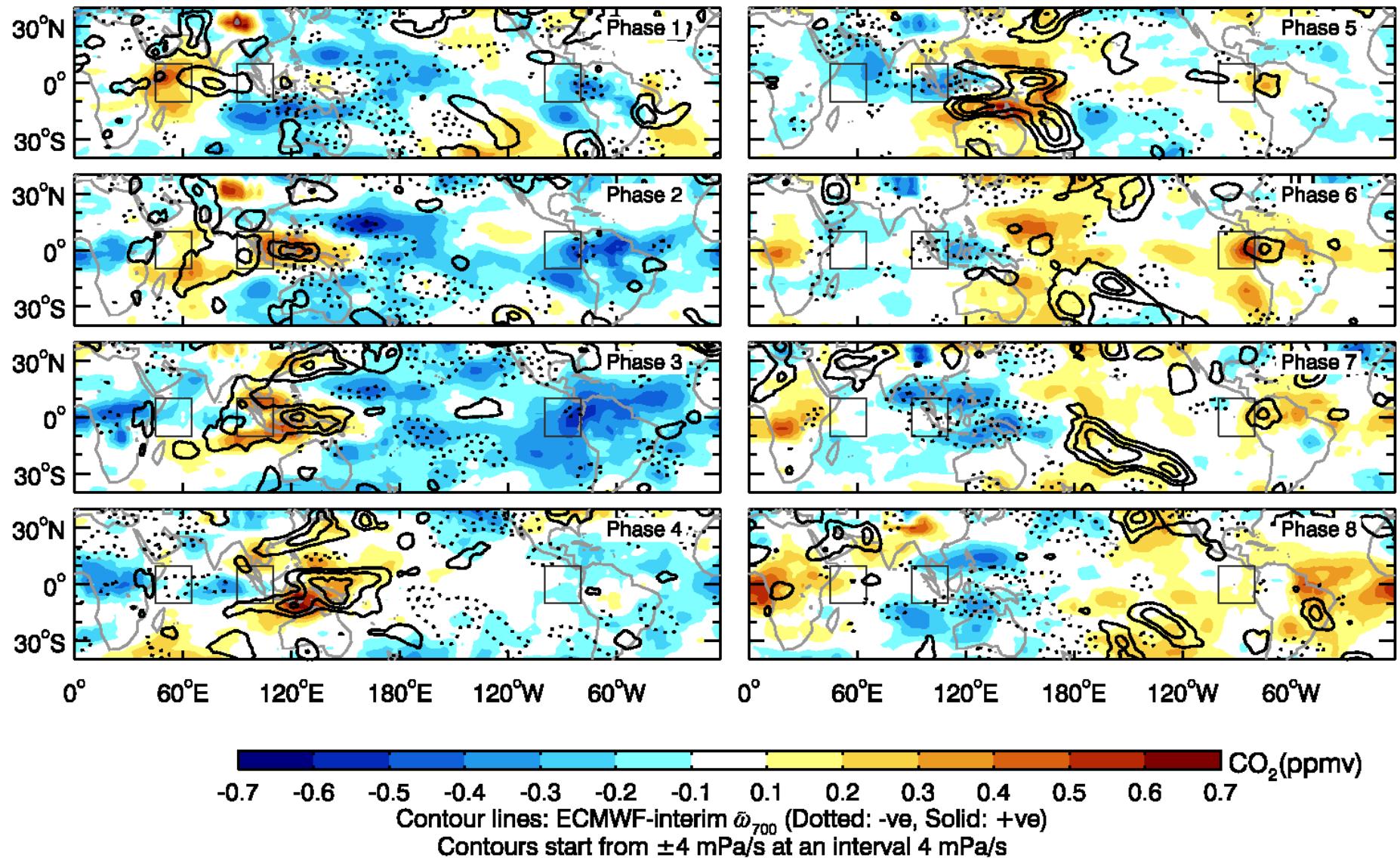
RMM PHASE SPACE FOR AIRS PERIOD 11/2002 - 02/2010



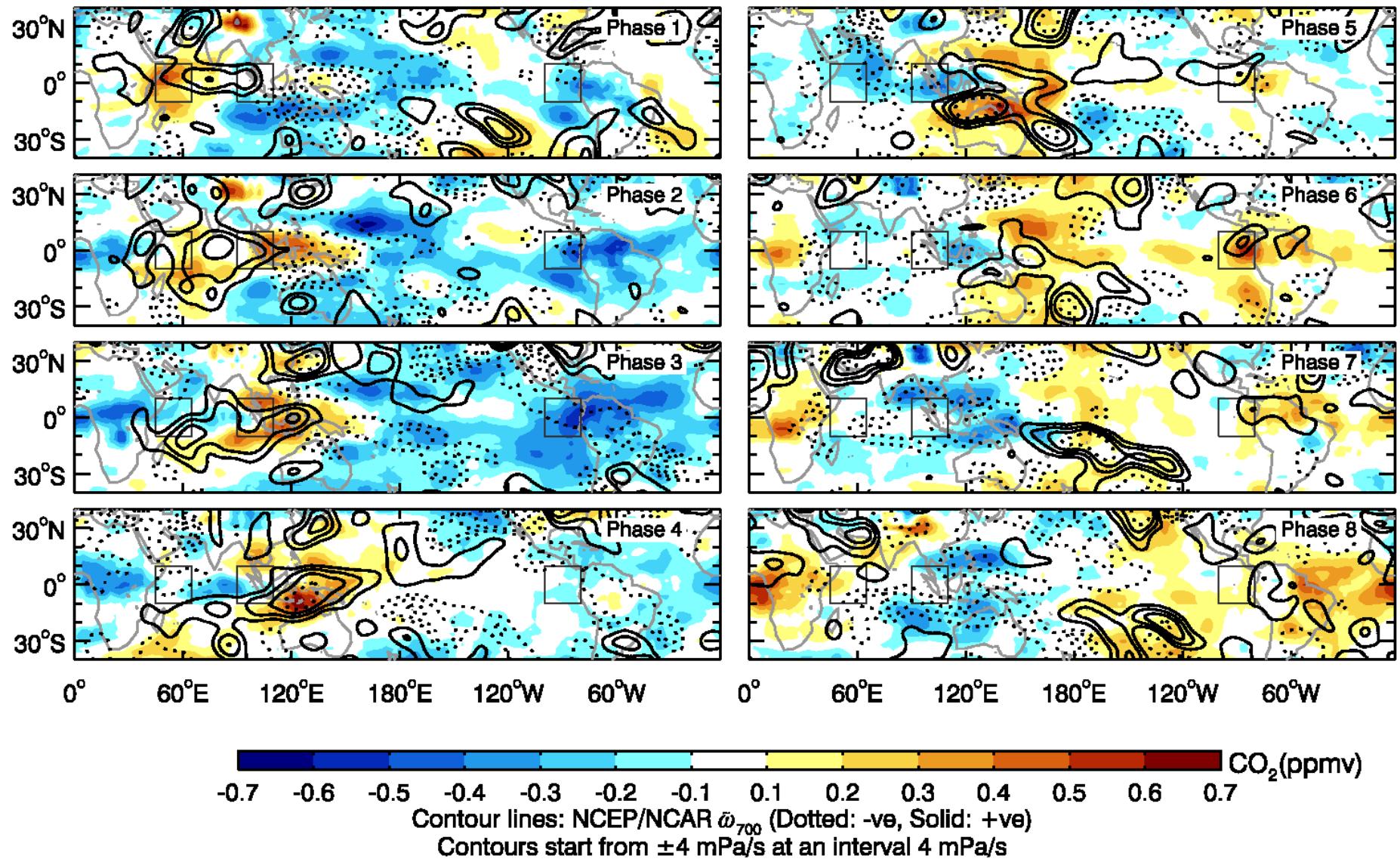
MJO-RELATED AIRS CO₂ ANOMALY



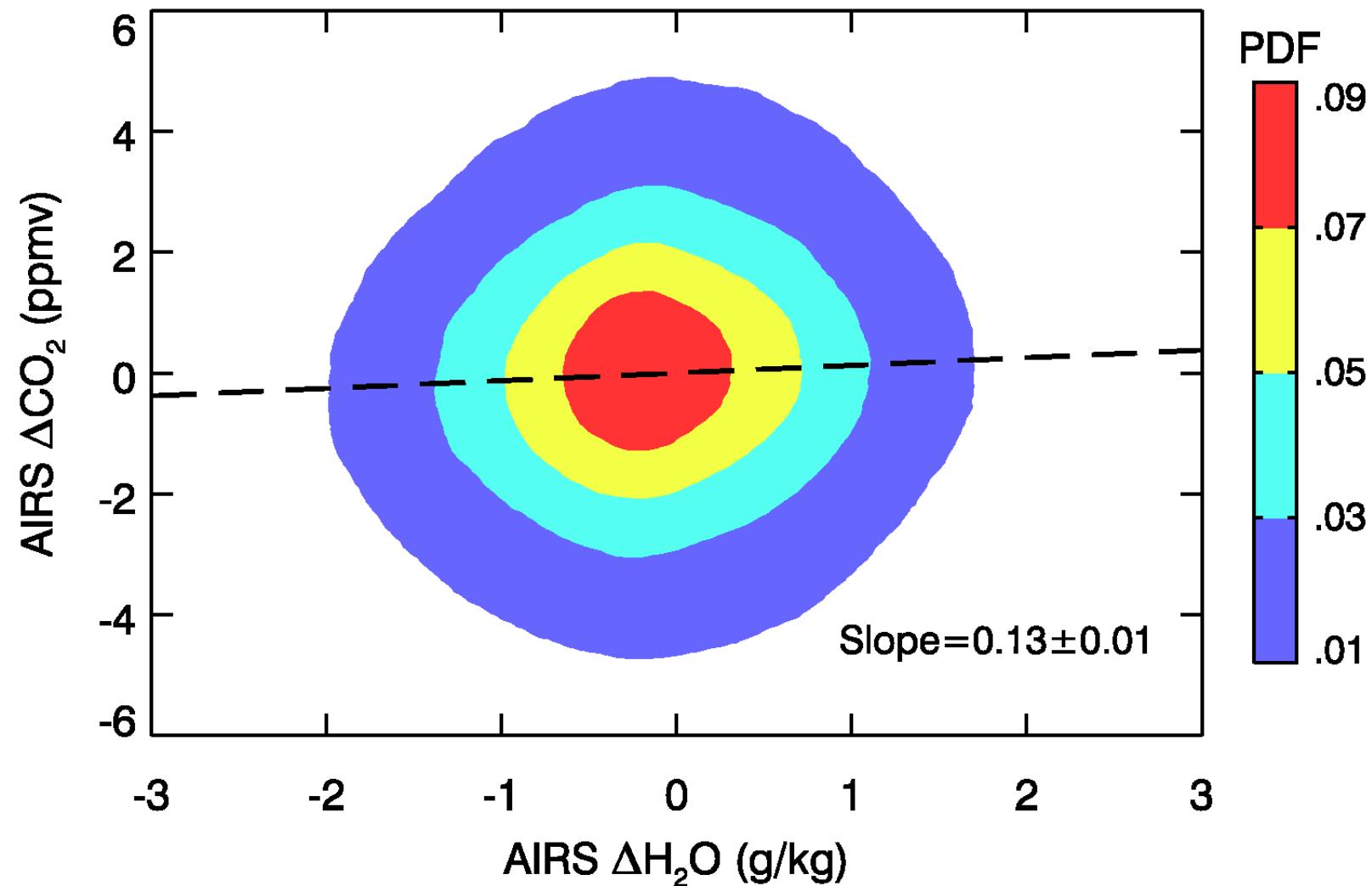
MJO-RELATED AIRS CO₂ ANOMALY



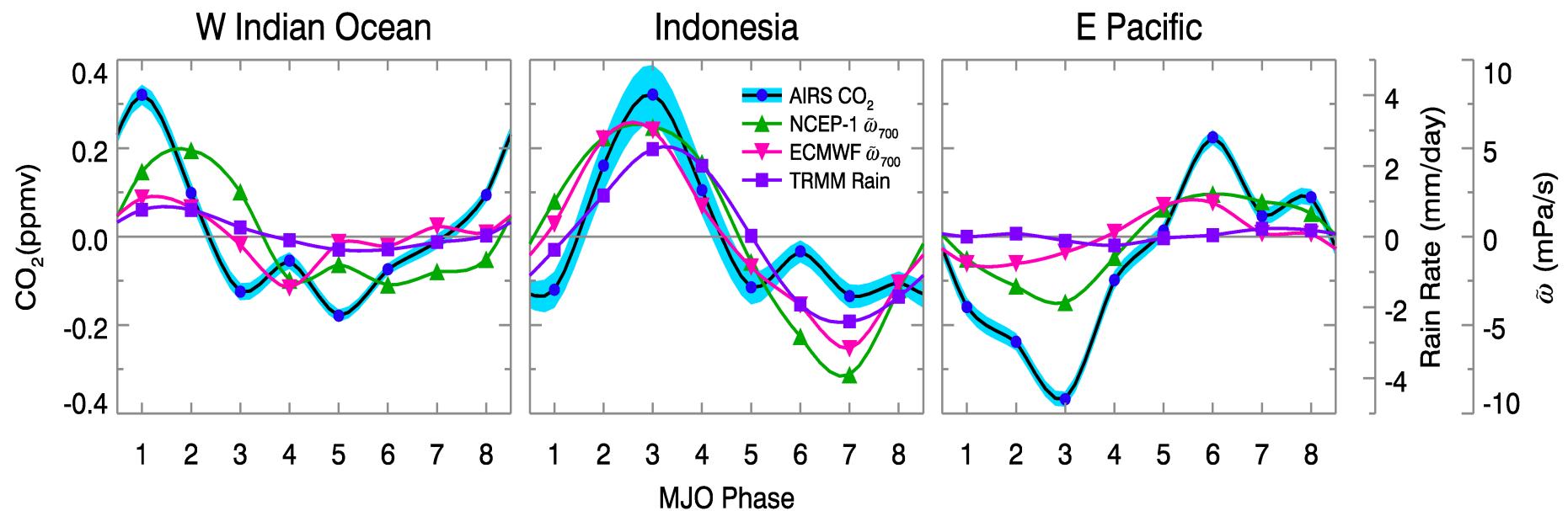
MJO-RELATED AIRS CO₂ ANOMALY



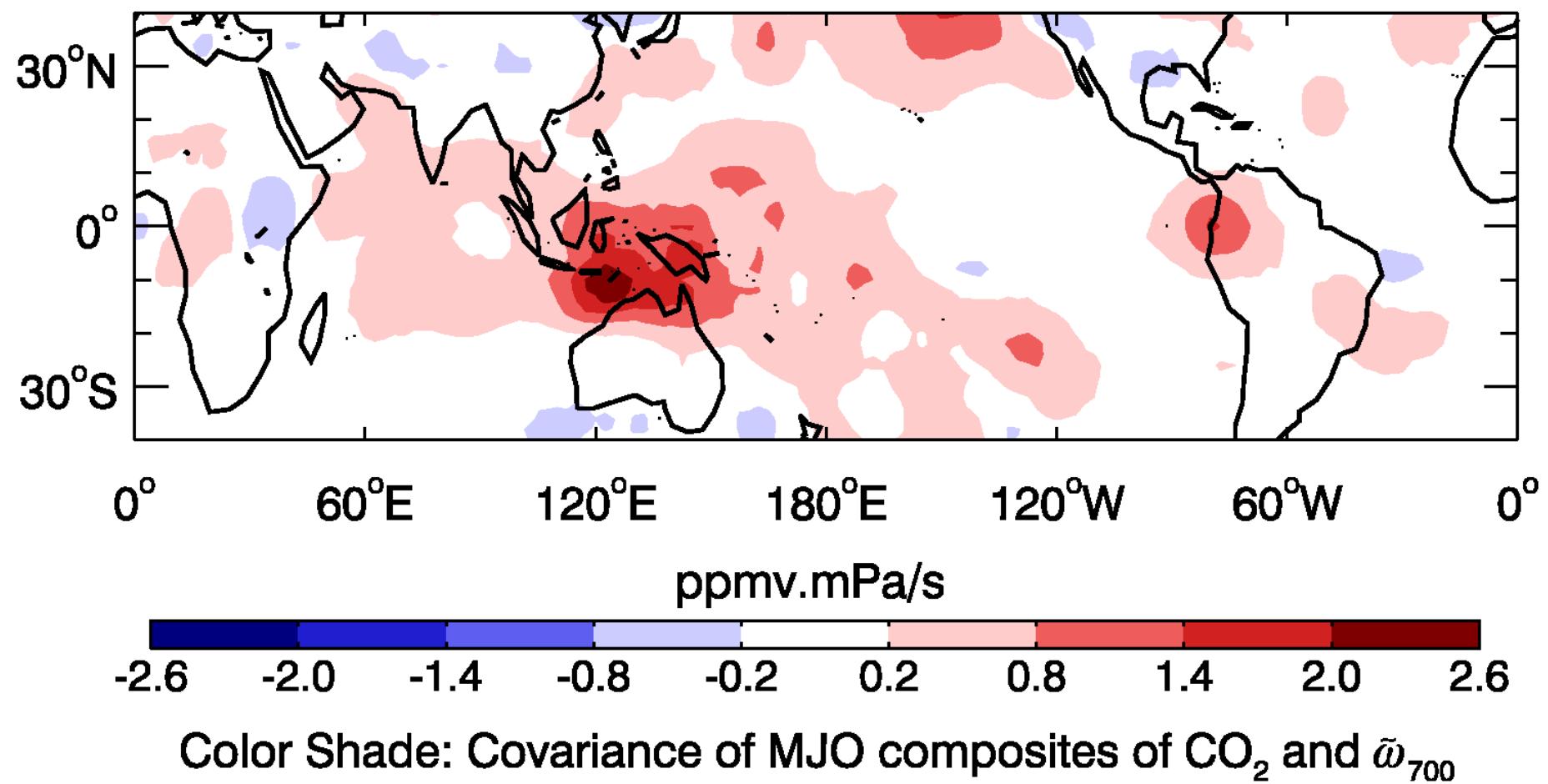
SCATTER PLOT OF AIRS L3 CO₂ AND H₂O DAILY ANOMALIES



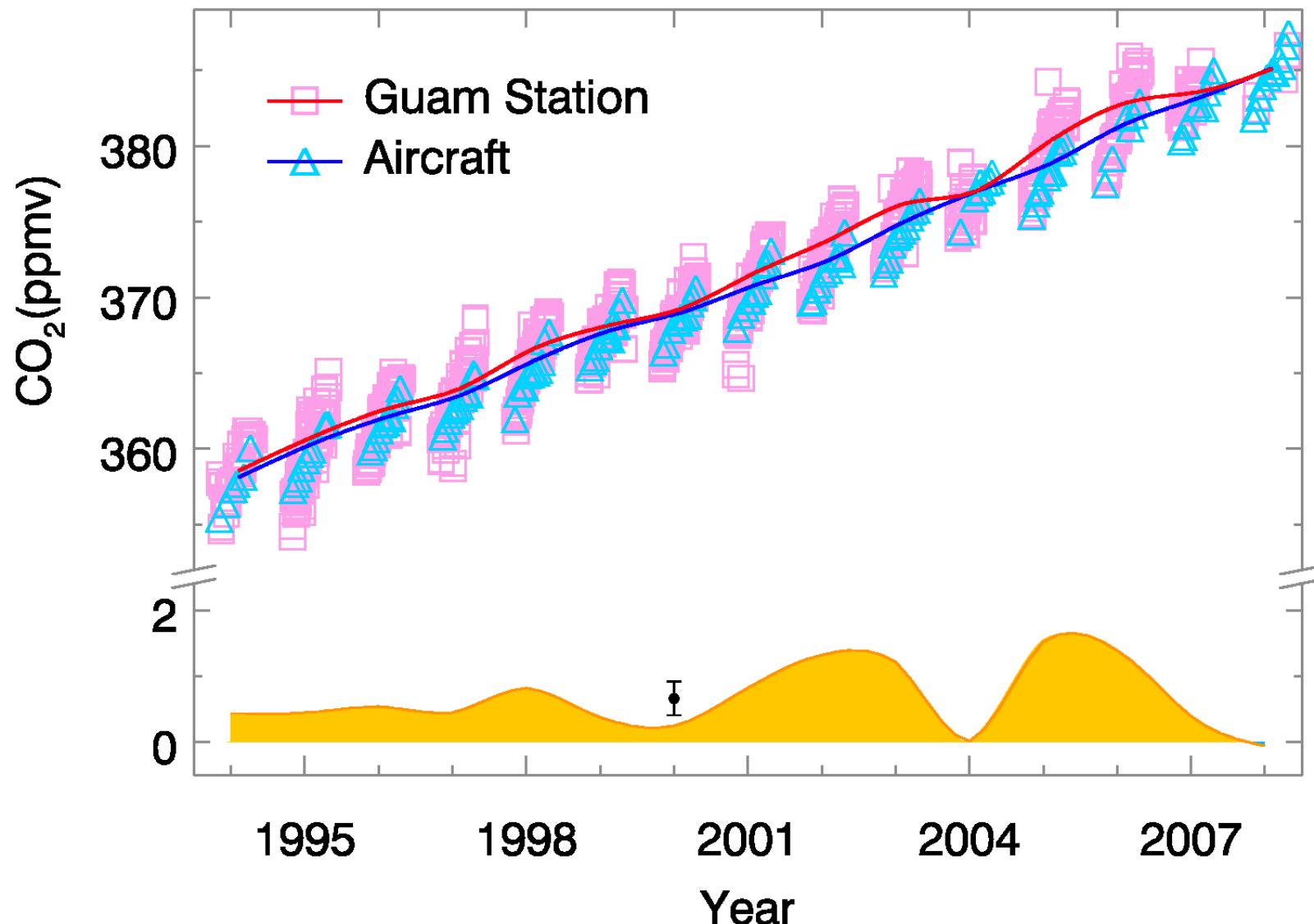
COMPOSITE MJO TIME SERIES OF AIRS CO₂, REANALYSIS 700-hPa VERTICAL VELOCITY AND TRMM RAINFALL



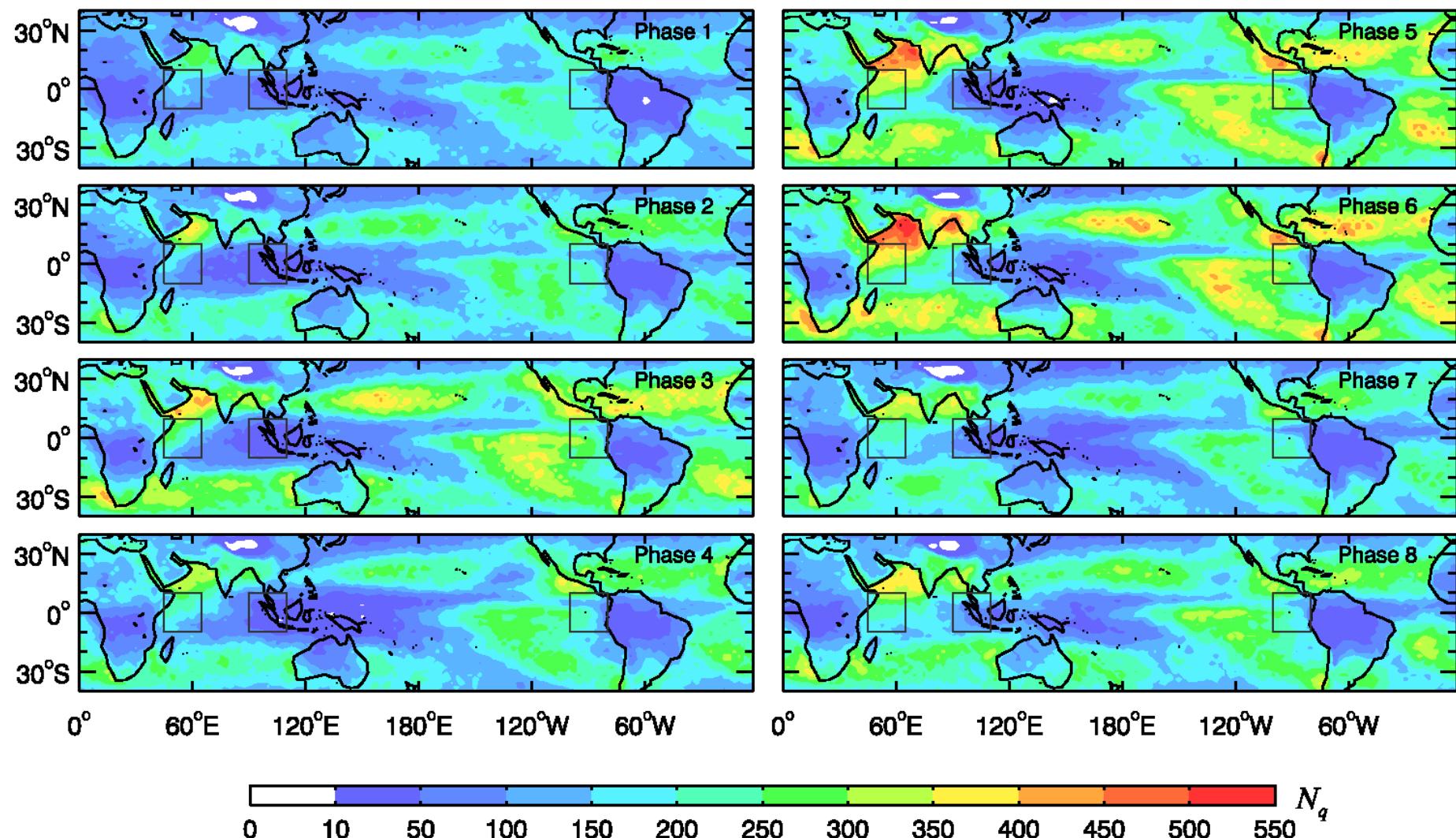
COVARIANCE OF MJO ANOMALIES OF CO₂ AND 700-hPa VERTICAL VELOCITY



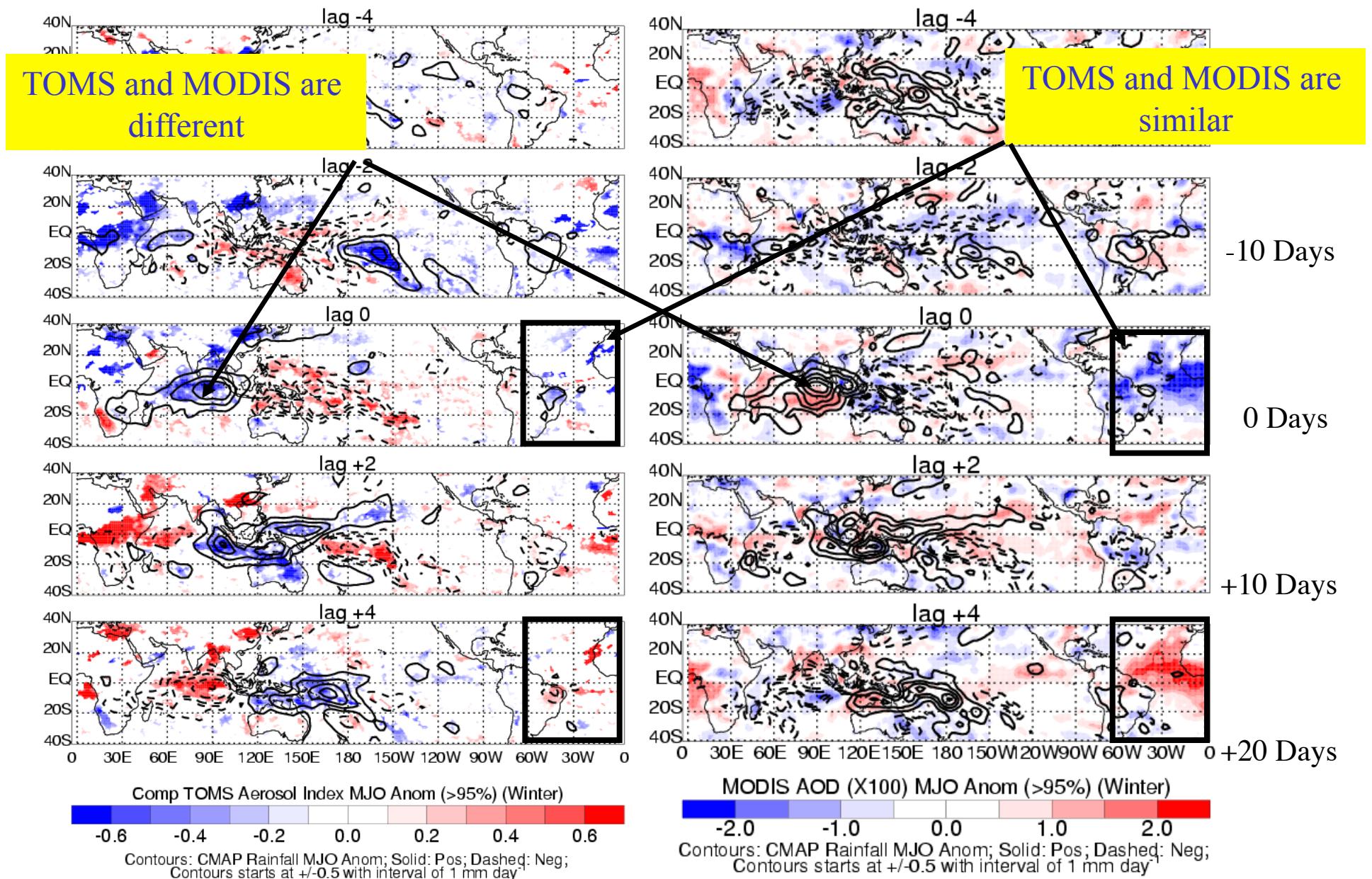
COMPOSITE MJO TIME SERIES OF AIRS CO₂, REANALYSIS 700-hPa VERTICAL VELOCITY AND TRMM RAINFALL



TOTAL NUMBER OF AIRS CO₂ RETRIEVALS FOR EACH PHASE OF THE COMPOSITE MJO CYCLE AT EACH GRID



AEROSOL MJO ANOMALIES

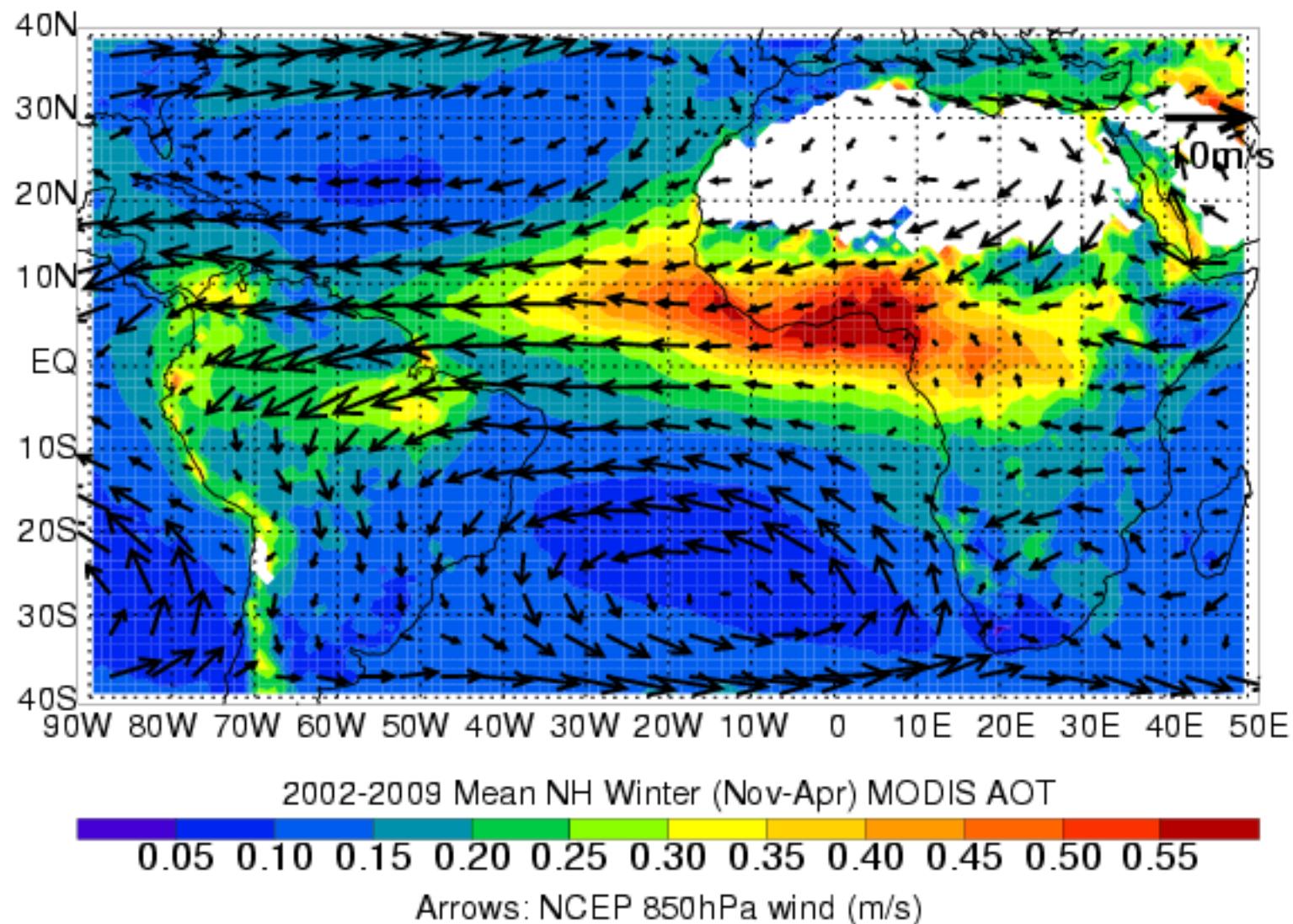


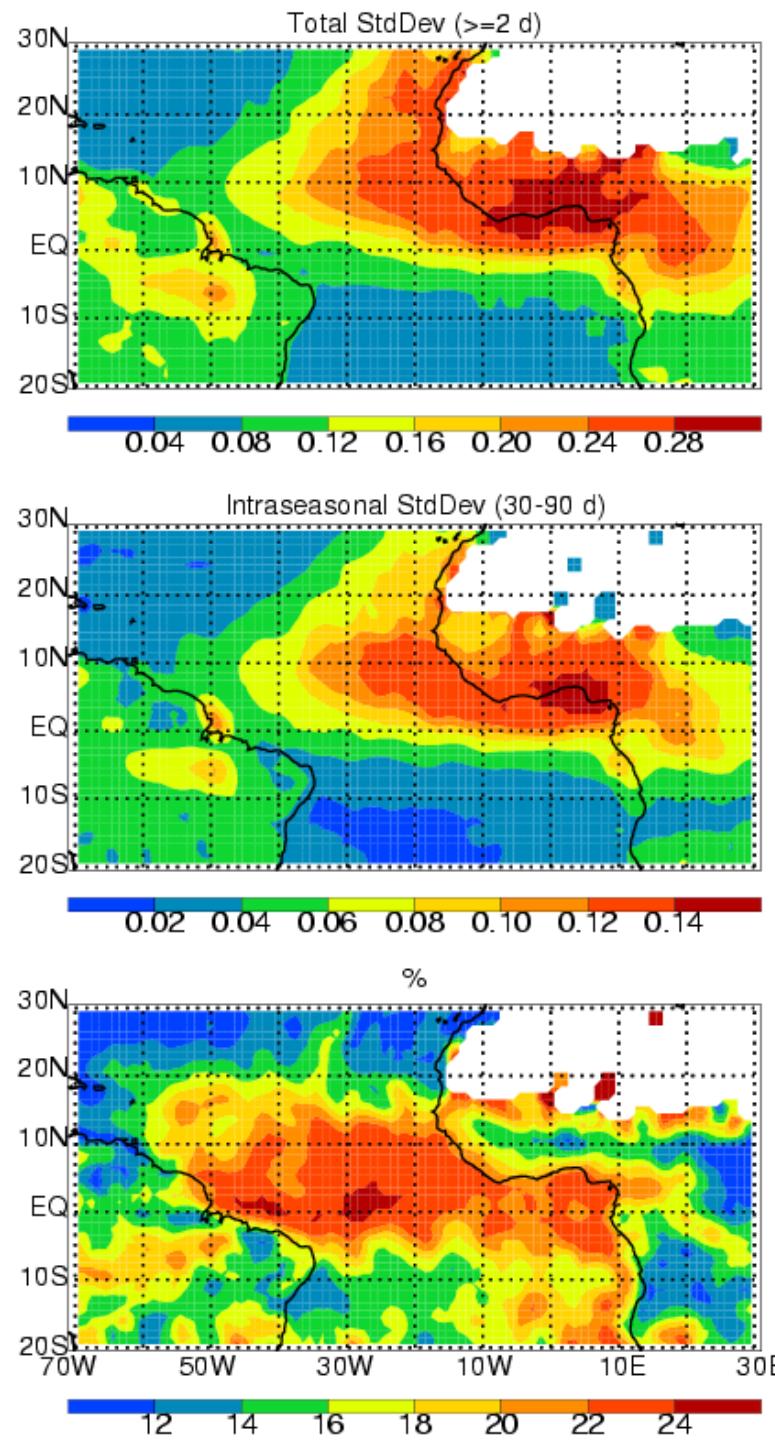
TOMS

Figs. 2 & 4 of Tian et al. [2008]

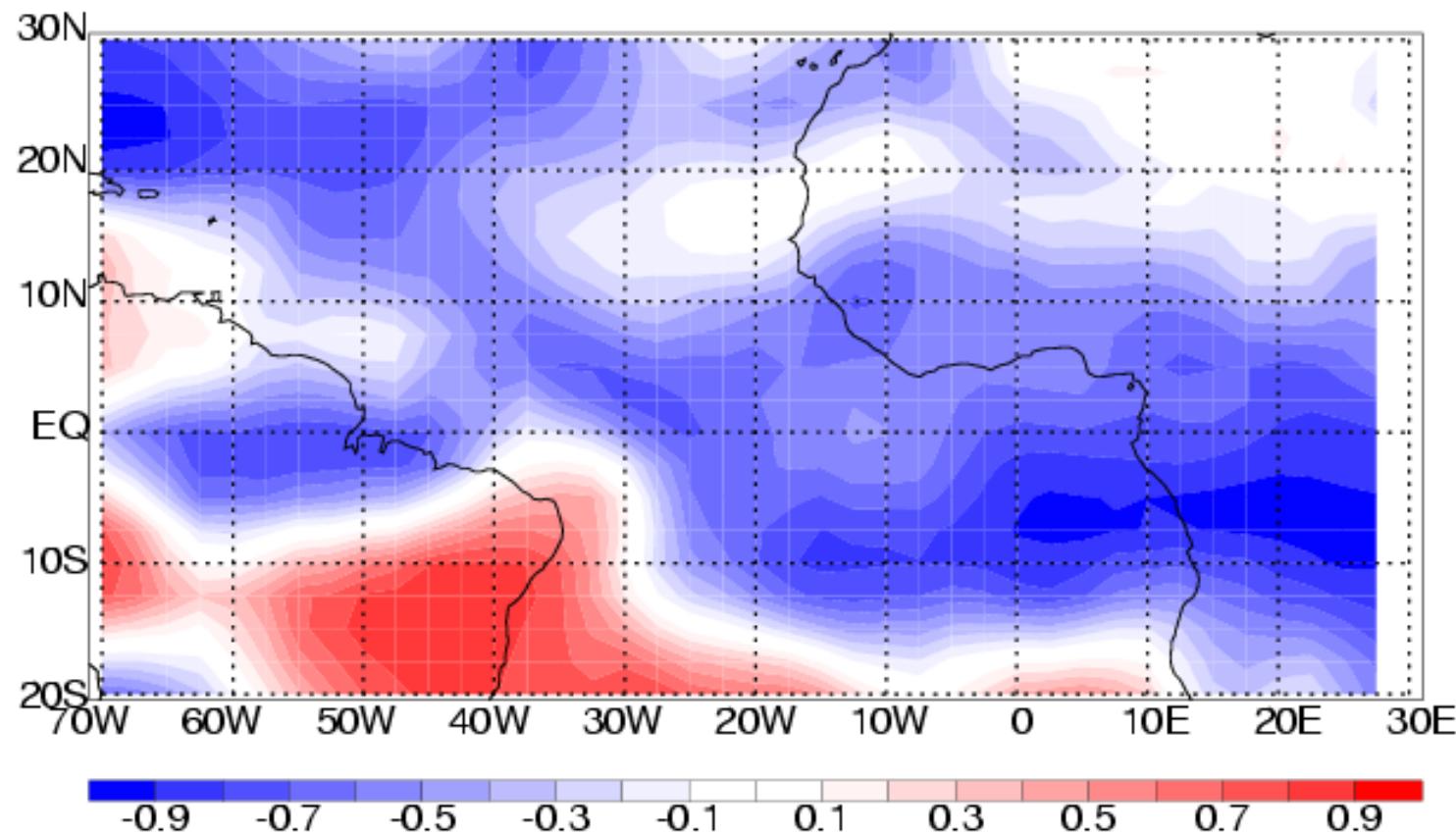
MODIS

7-YR MEAN BOREAL WINTER MODIS/AQUA AOT AND NCEP 850-hPa HORIZONTAL WINDS



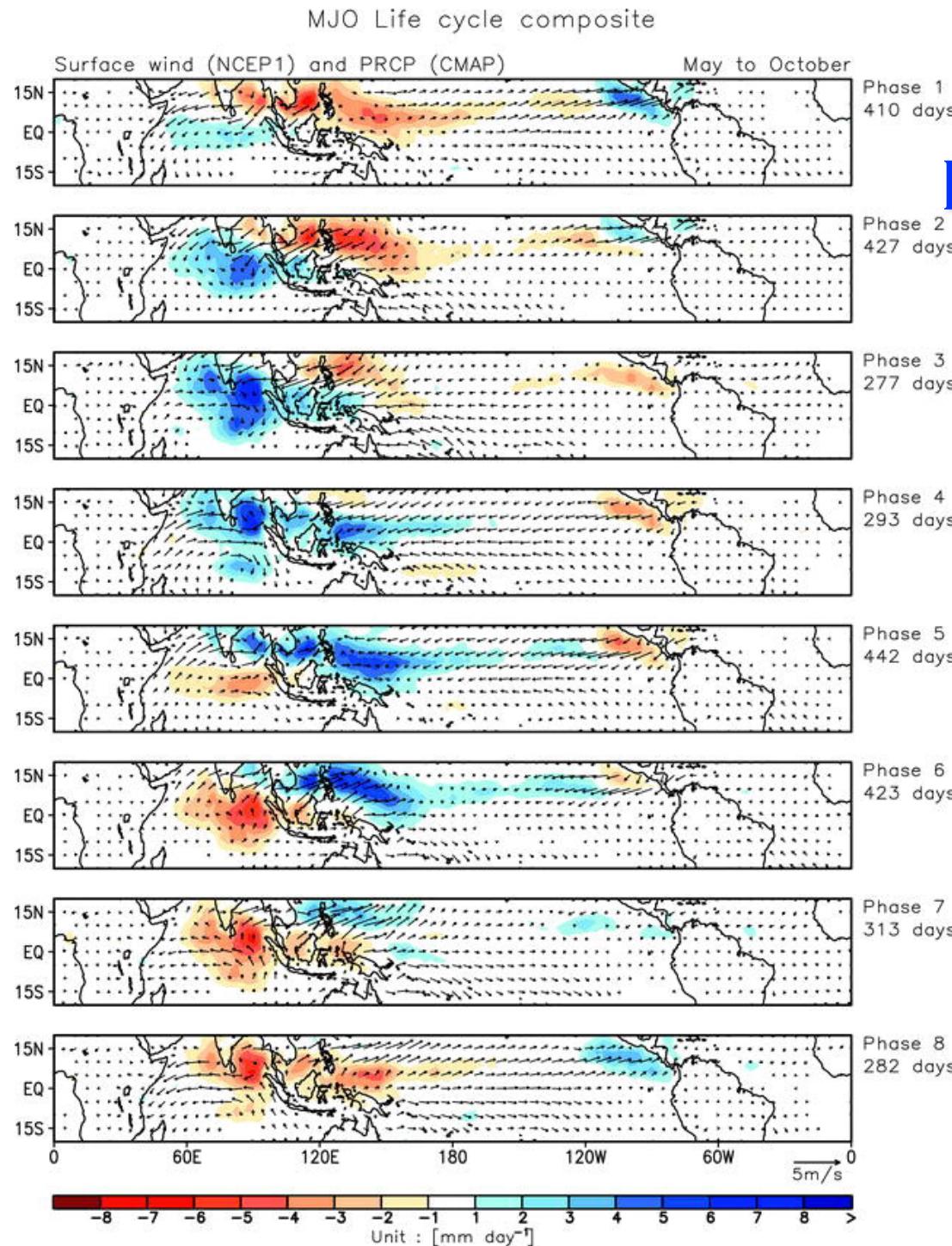


LINEAR CORRELATION COEFFICIENT BTW MODIS AOT AND NCEP 850-hPa ZONAL WIND COMPOSITE MJO ANOMALIES



Negative (positive) correlation means that westerly anomalies induce negative (positive) AOT anomalies or easterly anomalies induce positive (negative) AOT anomalies

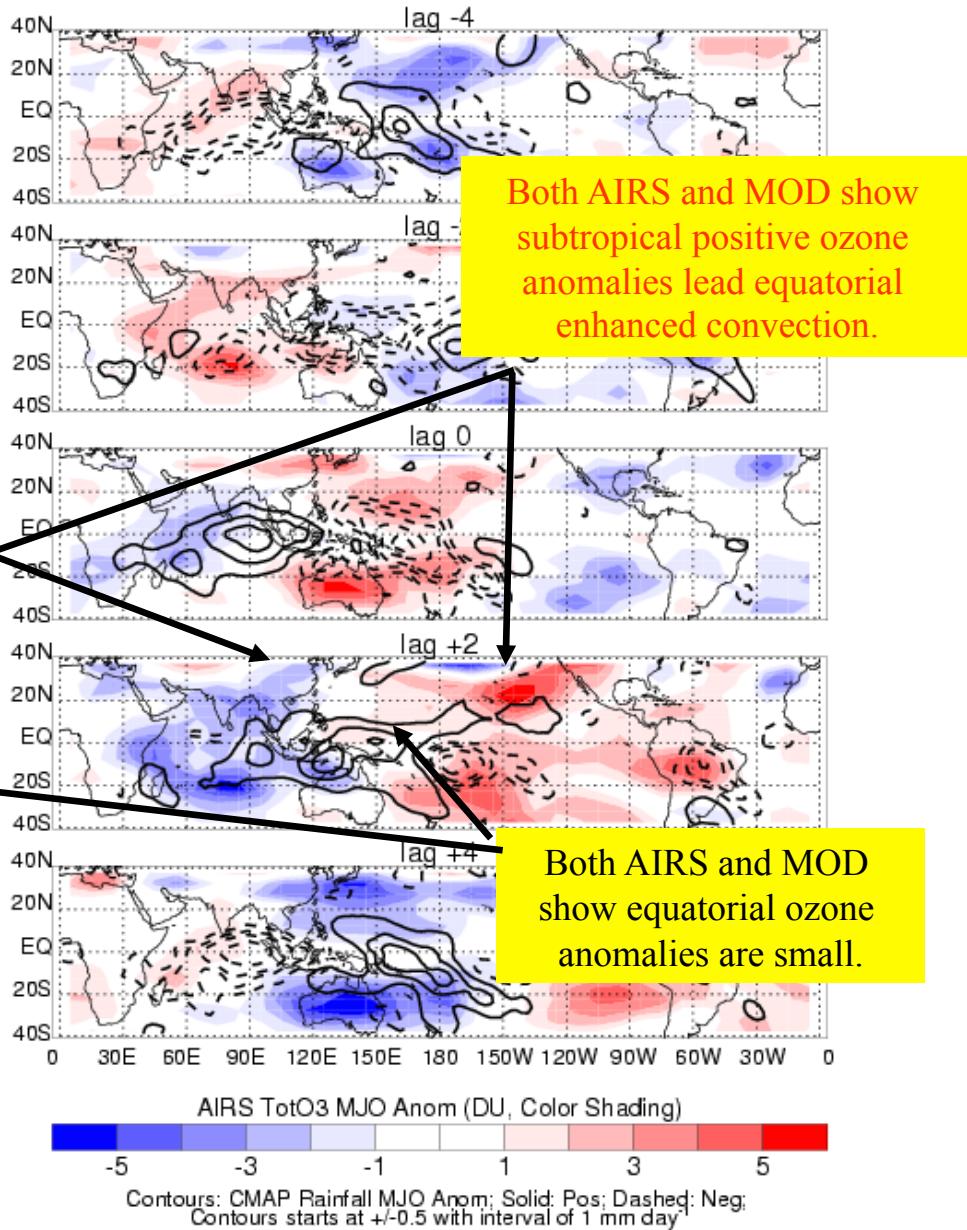
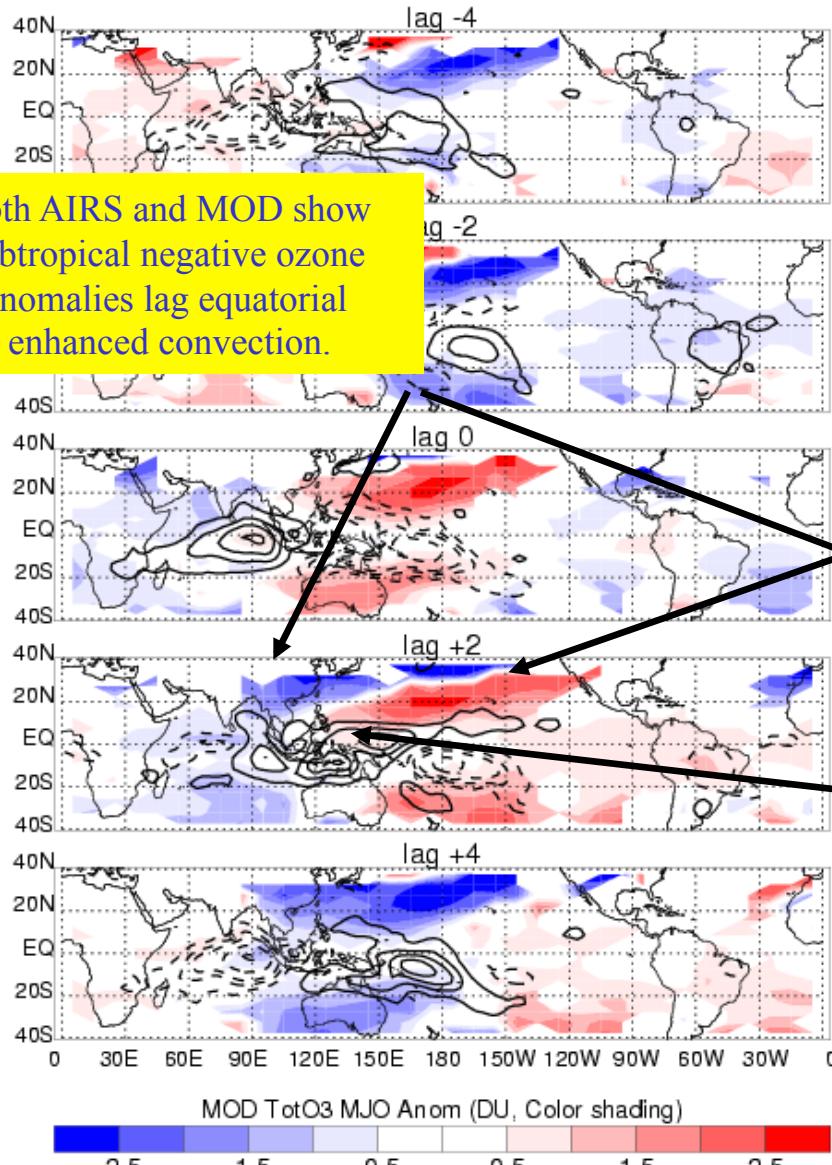
A COMPOSITE MJO CYCLE IN N.H. SUMMER (MAY-OCT)



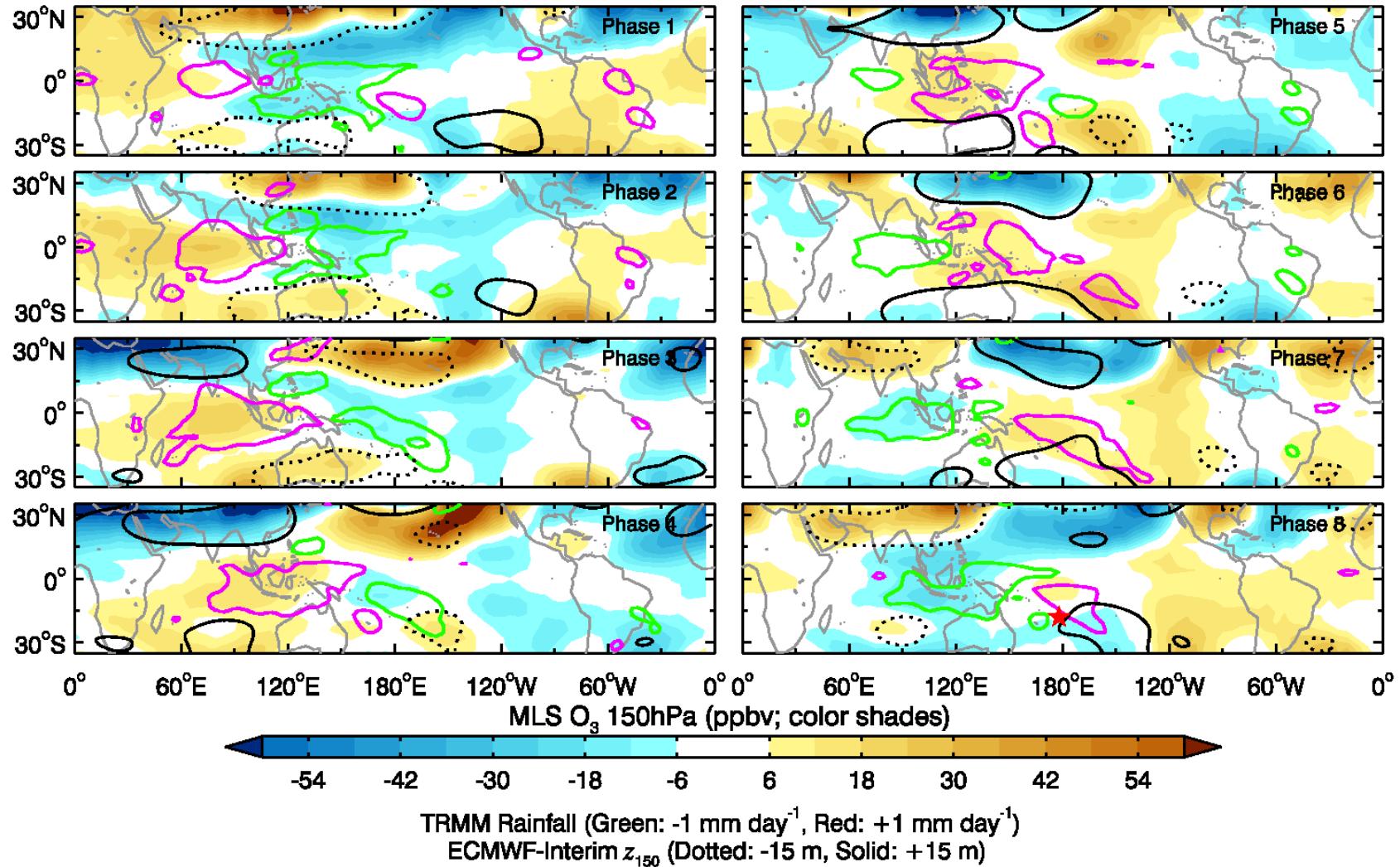
- Rainfall (convection) anomalies propagate *northeastward* and mainly affect the tropical eastern hemisphere.
- Surface wind anomalies can affect the global tropics.

Fig. 11 of Waliser et al. [2009]

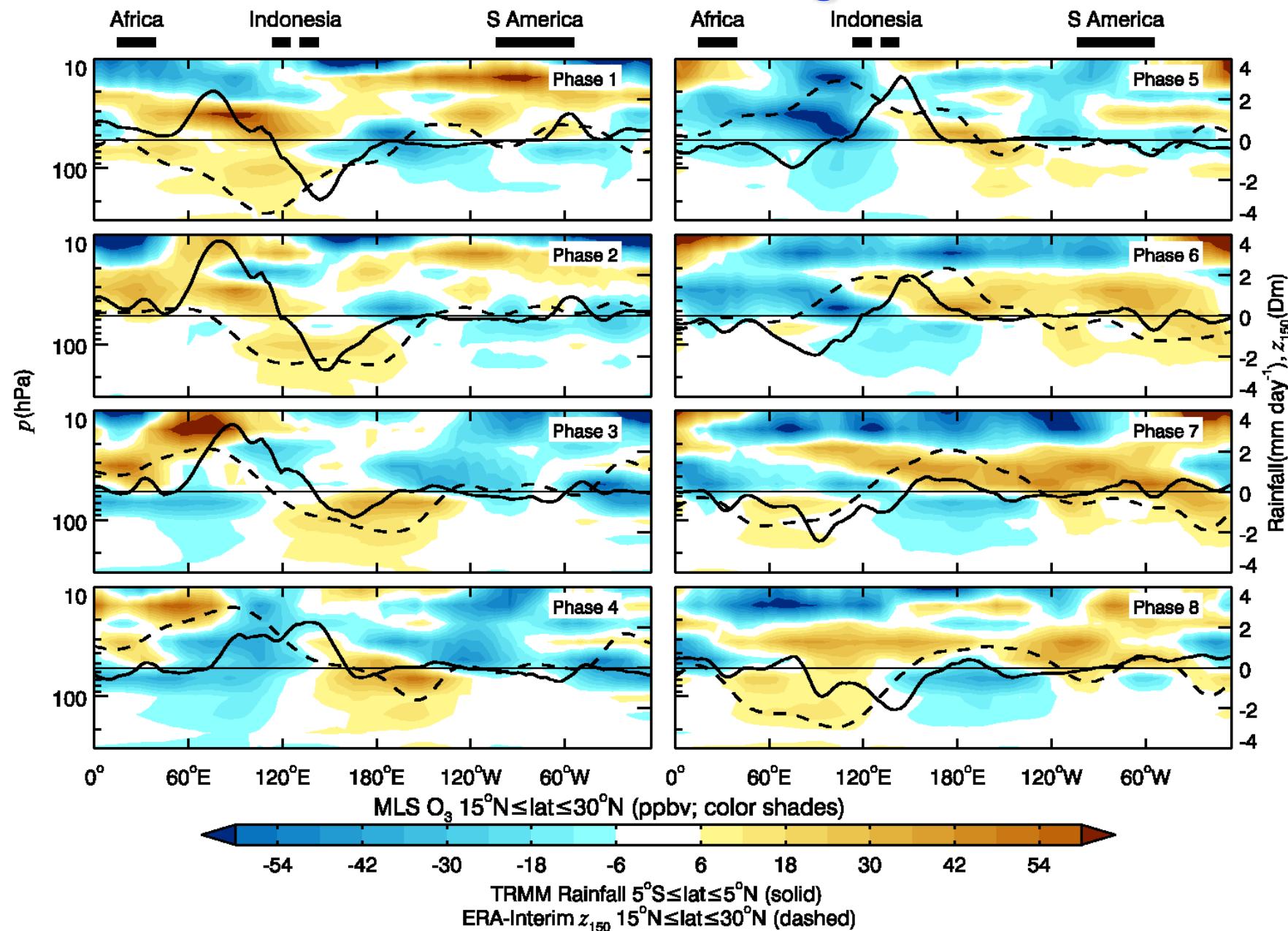
TOTAL O₃ MJO ANOMALY



150-hPa MLS O₃ MJO ANOMALY

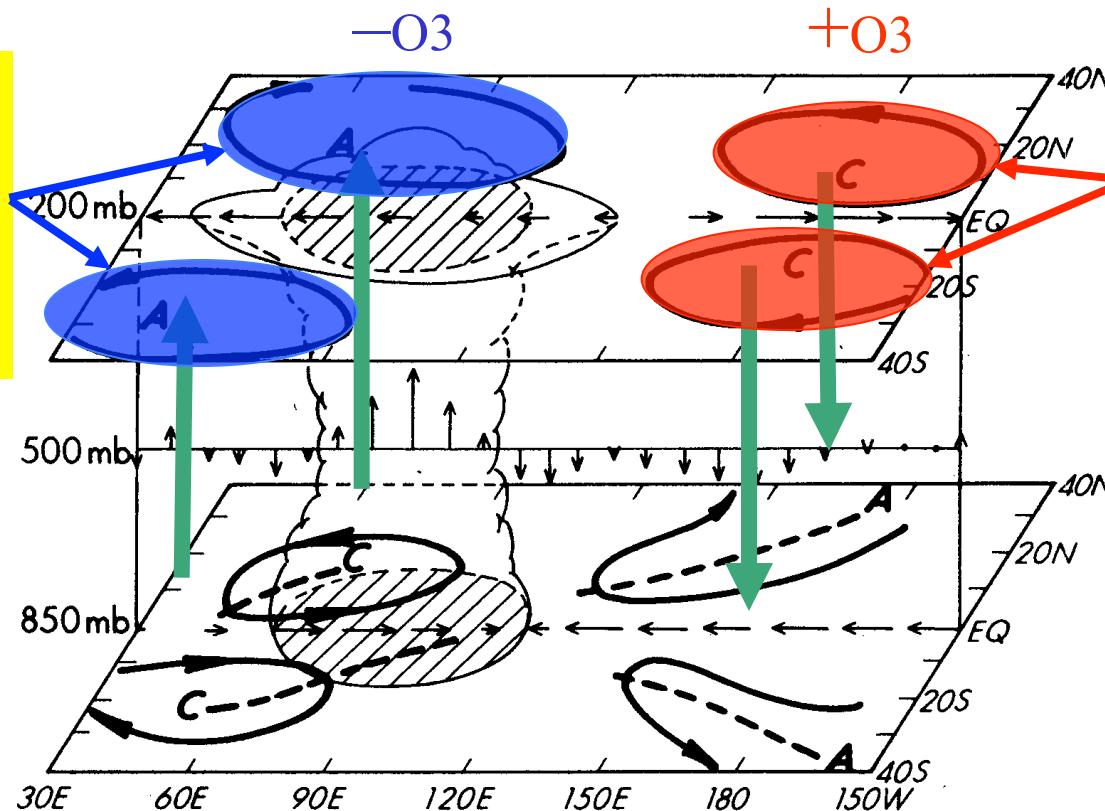


NH SUBTROPICAL MLS O₃ MJO ANOMALY



SCHEMATIC OF THE TOTAL O₃ ANOMALIES AND THEIR CONNECTION TO THE MJO

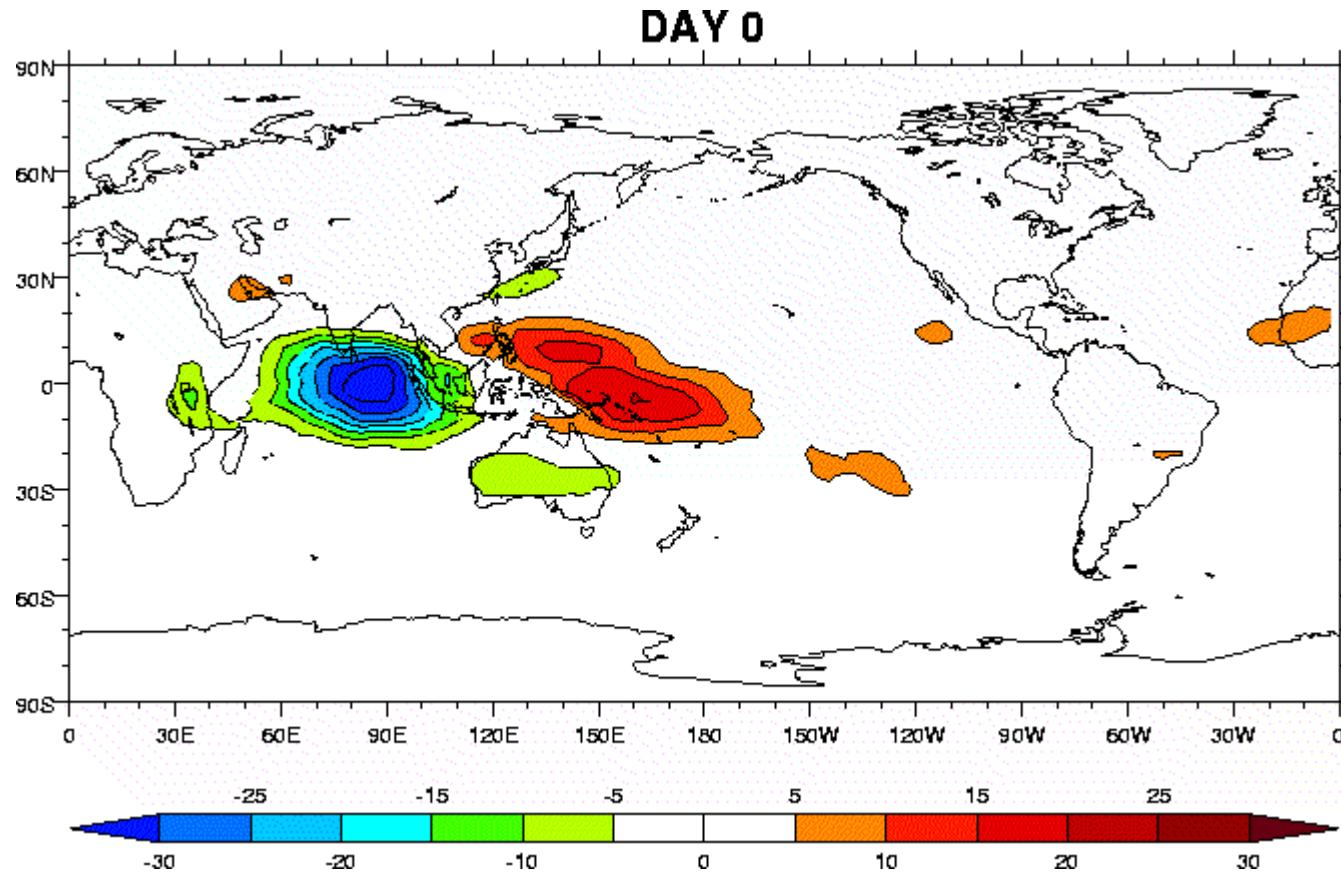
Subtropical UT anticyclones lift the TTL and O₃-poor tropospheric air to decrease the total ozone



Subtropical UT cyclones lower the TTL and O₃-rich stratospheric air to increase the total ozone

The cloud symbol indicates the convective center. Arrows represent anomalous winds at 850 and 200 hPa and the vertical motions at 500 hPa. "A" and "C" mark the anticyclonic and cyclonic circulation centers, respectively. Dashed lines mark troughs and ridges. Tian et al. [2007]

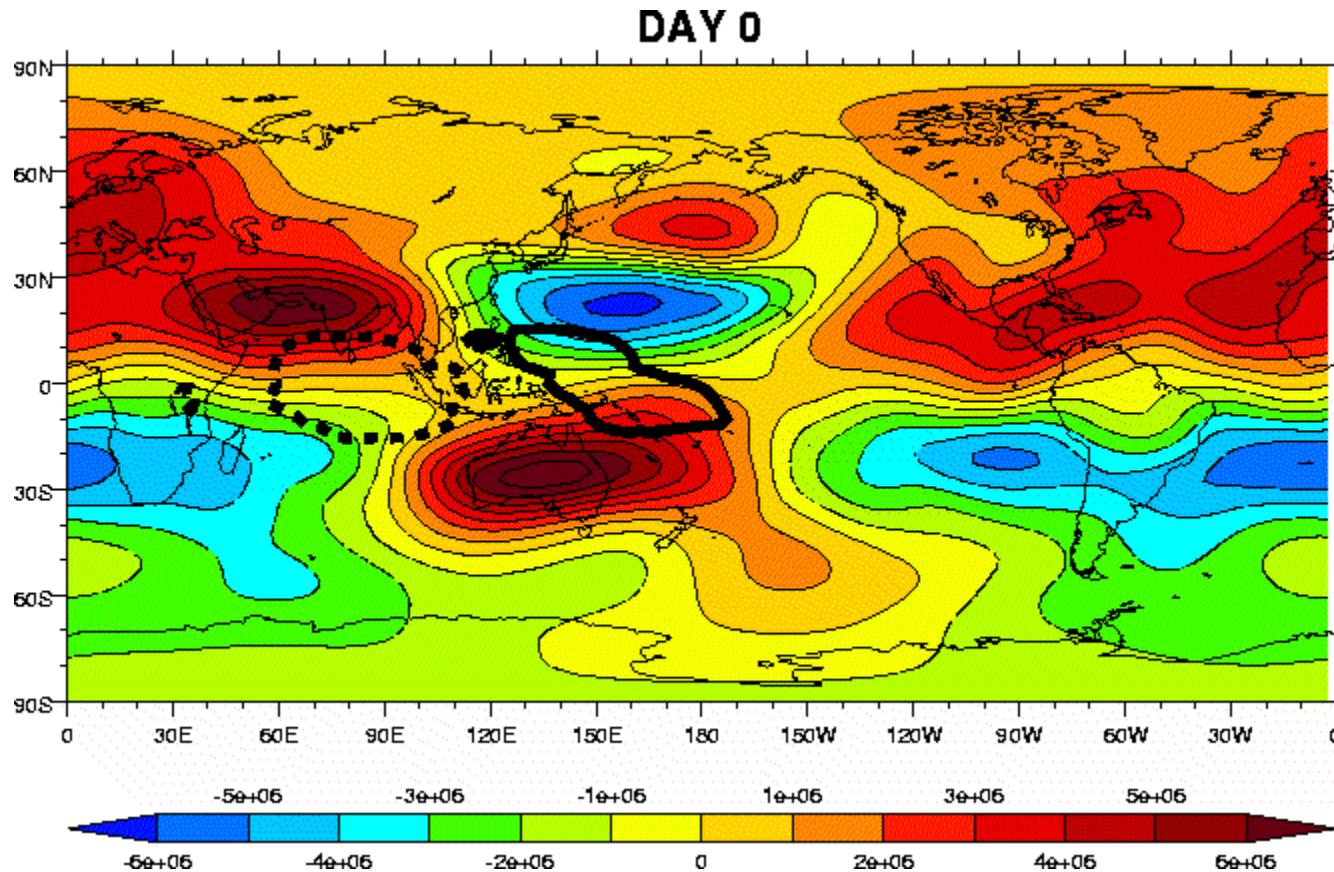
A TYPICAL MJO IN N.H. WINTER



OLR anomalies (W m^{-2}); Blue = enhanced convection; Red = reduced convection

The images are spaced approximately 3 days apart and one whole cycle lasts approximately 48 days. From [Matthews 2000](#).

200-HPa STREAM FUNCTION ANOMALIES



The color red denotes positive anomalies of stream function, an anticyclone (a cyclone) in the northern (southern) hemisphere, while the color blue indicates negative anomalies of stream function, a cyclone (an anticyclone) in the northern (southern) hemisphere. The superimposed solid (dashed) black line denotes the OLR MJO anomaly of +10 (-10) W/m², indicating suppressed (enhanced) convection. The images are spaced approximately 3 days apart and one whole cycle lasts approximately 48 days. From *Matthews et al. [2004]*.